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CONTENTS

THE POLARIS FLEET

The test firings by H.M.S. *Revenge* have completed the initial practice program for each of Britain's four Polaris submarines. All eight firings were completely successful and the 100% record has demonstrated the impressive reliability and accuracy of the Polaris weapon system, as well as proving the British designed and built submarines. After her return to Faslane last month, the *Revenge* started to prepare to join the operational Polaris fleet alongside H.M. Ships *Resolution, Repulse* and *Renown*.

This brings to full fruition the largest single project ever undertaken by the Royal Navy, which began in 1962 when H.M. Government decided that the Navy should build, man and operate a force of nuclear propelled ballistic missile submarines. The achievement of this programme is remarkable for the way in which four highly sophisticated British warships, incorporating complete U.S. Polaris missile systems, have been built in the U.K. within an extremely tight timescale, while the overall costs of the whole project have been kept within the original budget estimate of £350 million made seven years ago. This total bill covers the submarine, their weapons and H.M.S. *Neptune,* the Clyde Submarine Base at Faslane and Coulport, built to maintain and run them. The project has been an outstanding example of U.S.N./R.N. co-opertion, which started at its inception and still continues.

All four boats in the Polaris force have the two-stage A.3 ballistic missiles with a range of 2,500 nautical miles. Their re-entry system consist of three bodies and the warheads are British designed and produced in the U.K. under the direction of the Ministry of Technology.

The submarines were designed by the Navy Department of the Ministry of Defence and built entirely in the U.K. (the *Resolution* and *Repulse* by Vickers, Barrow, and the *Renown* and *Revenge* by Cammell Laird at Birkenhead). Apart from their 16 Polaris missiles, each carries six 21 inch torpedo tubes. Their construction has involved co-ordination of effort by hundreds of firms, both British and American, in the manufacture of components. To achieve this, a special project-type organisation initially under Vice-Admiral Sir Hugh Mackenzie, K.C.B., D.S.O.*, D.S.C., was set up employing the latest management techniques.

Each submarine has two crews, port and starboard, and each consists of some 147 officers and ratings who rotate on the patrol cycle. On completion of patrols, the submarines return to base to change crews, re-store and maintain. At appropriate stages the boats will go into Rosyth for re-fitting. H.M.S. *Resolution* is currently in Rosyth Dockyard having just started her first refit.

Another of the remarkable aspects of the Polaris programme has been the building of the Base and Armament Depot. To store, maintain and process the submarines and their missiles, has involved carving out a new landscape from the Scottish hillside. The operational area of the Base includes a specially designed jetty for alongside berthing of the nuclear submarines, a floating dock and a Polaris school for training the crew " round the clock on a shift system ". Workshops have been built and equipped to service all the complex equipment fitted in the boats, stores buildings house thousands of spare parts—computer controlled—and supplies of food and oil fuel necessary to keep the submarines and Base operational.

The Royal Navy took over the nation's contribution to the Western Strategic Nuclear deterrent from the Royal Air Force in July 1969. Behind this simple fact lies a remarkable story of planning and execution, outstanding co-operation from the United States, and dogged endeavour, which has provided an apposite counterpart to the courage, skill and endurance which marks the men of the Submarine Service of the Royal Navy who man the Polaris Fleet.

RECORD SUBMARINE ESCAPES

Headlines from the National Press recently heralded yet another outstanding achievement in the field of underwater activities by the Royal Navy and the scientific staff of the Royal Naval Physiological Laboratory.

In mid-July 1970 in the sea off Malta G.C. a team of Submarine Escape Instructors from H.M.S. *Dolphin*, successfully carried out a series of escapes from H.M. Submarine *Osiris*, culminating in a world record at a depth of 600 ft (the previous record escape being from 500 ft in 1965 also by Instructors from H.M.S. *Dolphin*).

That record depths were achieved during the escapes was incidental, for the object of the trials was to further calibrate and test improvements in the equipment and to collect physiological and scientific data under actual escape conditions.

The achievement of these Submariners under the leadership of Lt. Cdr. Matthew Todd provides yet another example of the co-operation and confidence that exists between Constructors, Scientists and Serving Members of Her Majesty's Navy. This teamwork has made it possible for the Royal Navy to become the first in the world able to safely carry out the removal of men from a submarine from depths down to the Continental Shelf.

This ability to accomplish submarine escape from such depths gives some idea of the quite remarkable progress that has been made during the past few years.

At the present time 12 overseas navies have purchased submarines of the Oberon class, possibly the finest conventional submarines in the world to-day and each of which is fitted with the one man escape system used in the recent trials. So this latest success is bound to give an additional boost to overseas sales of Oberon class submarines.

The National Press has dealt with the magnificent part played by the whole of the Escape Tank Instructional Staff in performing this latest series of escapes.

The parts played by the staff of the Director General Ships in the design of the Escape Tower and equipment, also that of the Research carried out by the staff of the Royal Naval Physiological Laboratory over many years must of course pale in comparison with the actual deeds of the Escape Team.

However, the work at the Laboratory has come to fruition mainly under the Directorship of Superintendent Dr. H. J. Taylor and of Dr. H. V. Hempleman, who succeeded him two years ago.

The majority of the experimental work during the last 15 years leading to the present achievement has been carried out by Mr. W. J. Eaton, Experimental Officer, and Surgeon Commander E. E. P. Barnard, R.N.

REDUCING THE ECHOING AREA (Radar Cross-Section) of Slotted WAVEGUIDE ANTENNAE

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Abstract

This article deals, chiefly, with echoing area measurements made on straight and curved 'X' Band slotted waveguide antennae. It is shown that a 15 dB reduction in echoing area can be achieved by bending an antenna with a 1·5m aperture into a curve of 3·5m radius.

The calculation of slot pitches and other details of curved slotted arrays is also given.

Desmond Hanan has been involved with Radars and Radar Aerials since 1940 when he joined H.M. Signal School, Portsmouth to work on some of the early Naval R.D.F. equipments. In 1948 he joined the project team concerned with the design and development of the Type 984 Radar Aerial for which he invented and developed the multiple beam scanning system.

For 10 years prior to December 1969 he was a member of the Aerial Research Division at A.S.W.E. investigating, amongst other things, the properties of linear arrays at 'X', 'S' and 'L' Band frequencies.

He is now head of a section dealing with Post Design problems on Naval Surface Surveillance Radars.

Introduction. The purpose of the investigation discussed in this article was to determine the extent to which the echoing area of antennae, consisting of stacked slotted waveguides, could be reduced by bending the waveguides into convex circular arcs.

The design of a bent 'X' Band end fed slotted array which would have a flat phase front, seemed quite possible for a radius of curvature not less than about two-and-a-half times the chord length of the array. This limiting value is set, in this case, by the slot spacings which are altered to compensate for the phase error introduced by the curvature and progressively diminish towards the load end of the array; the end slots being just over a slot length apart.

In order to determine what order of reduction in echoing area could be expected from slightly curved surfaces, the re-radiation patterns of a thin metal plate, flat and bent, were measured. The results were encouraging and therefore the design and manufacture of three curved slotted arrays was undertaken.

To the best of the author's knowledge there is no published data on the echoing area of slotted arrays and since a standard was required to assess the improvement due to bending, a series of experiments was conducted using existing single, two stack and three stack flat vertically polarised arrays of the same length as the curved arrays. As noted later the power distribution along the flat arrays is not identical to the power distribution along the curved arrays but it is not considered that the difference affects the echoing area measurements. The three stack flat array was compared directly with the three stack curved array and absolute values were measured against standard corners of known echoing area. A single, flat, horizontally polarised array was also measured and the results, though not directly relevant to the main topic are of interest and are included in this report. A description and details of the curved array are given.

Test Procedure. The preliminary tests on the flat and curved plate were done on a short 'X' Band c.w. site (length 60ft.) the frequency of the transmitter being variable between 8000 MHz and 10000 MHz. The plate was supported on a polystyrene foam cylinder on top of a remotely controlled turntable, the turntable being shielded from the transmitter by sloping and angled screens of radar absorbent material. The background reflections were minimised by adjusting the angle of a sloping metal screen situated between the transmitting and receiving antennae and the turntable. The system was calibrated against a standard corner reflector ($\sigma = 11{\cdot}2\ \mathrm{m}^2$). The slotted arrays (length 1·5 m) were too long to be measured on the c.w. site and so were all measured using the only other suitable transmitter available, a pulsed fixed frequency radar. The frequency of the transmitter (9420 MHz) was well within the passband of both the flat and the curved arrays but not at the 'broadside' frequency in either case. The array under test was mounted on a remotely controlled turntable at a range of 350 ft. from the transmitter. A range gate was used to minimise unwanted echoes. The single and two stack slotted arrays were all measured using a monostatic system (*i.e.* transmitting and receiving on the same antenna), the three stack arrays were measured monostatically and bistatically (*i.e.* separate transmitting and receiving antennae, the latter being moved in an arc of 350 ft. radius round the target). The systems were calibrated against three standard corner reflectors ($\sigma = 11{\cdot}2\ \mathrm{m}^2$, $35{\cdot}4\ \mathrm{m}^2$ and $49{\cdot}2\ \mathrm{m}^2$).

Monostatic Measurements on a Flat and Curved Plate

These measurements were done using a 20 s.w.g. aluminium plate 40 cm long by 5·3 cm wide. The plate was lightly held by elastic bands against two fixed pillars near the ends of the plate, with a micrometer screw working against the centre of the plate.

The re-radiation pattern of the plate when flat was recorded and the maximum echoing area measured. The plate was then bent, by means of the micrometer screw, into a curve, convex towards the transmitter, the patterns recorded and echoing area measured at various micrometer settings (chord height). The change in maximum echoing area against chord height for both vertical and horizontal polarisation is shown in Fig. 1.

The theoretical echoing area (σ_F) of a flat plate at normal incidence, ignoring edge and resonance effects is given by:—

$$\sigma_F = \frac{4\pi A^2}{\lambda^2}$$

where 'A' is the area of the plate

where λ is the free space wavelength

For the plate in question $\sigma_F = 5{\cdot}7\ \mathrm{m}^2$

The averages of the measured values are:—

Vertical polarisation $\sigma_F = 6{\cdot}8 \pm 0{\cdot}5\ \mathrm{m}^2$

Horizontal polarisation $\sigma_F = 5{\cdot}1 \pm 0{\cdot}5\ \mathrm{m}^2$

The reduction in echoing area due to bending as shown in Fig. 1 was sufficiently encouraging to warrant the design and manufacture of three curved slotted arrays.

Monostatic Measurements on Single Flat Arrays

Two 5 ft, 58 slot linear arrays were measured, one horizontally polarised with inclined slots in the narrow wall and one vertically polarised with shunt displaced slots in the broad wall of the waveguide.

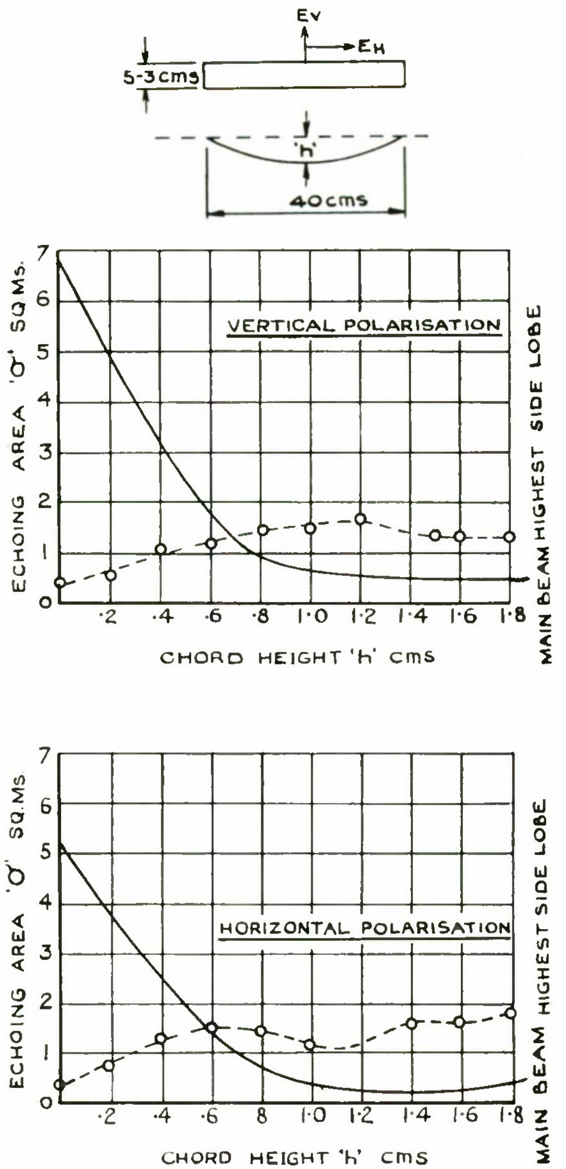

FIG. 1. Change in Echoing Area with Curvature Plate Size
40 cms × 5·3cms $\lambda = 3{\cdot}2$ cms.

Horizontally Polarised Array

(Inclined slots in the narrow wall, waveguide size 16.)

This array has an aperture distribution of $^1/_7 + ^6/_7 \, \mathrm{Cos}^2 \frac{\pi X}{a}$ where 'a' is the aperture length and '**x**' is the distance along the aperture. The power reaching the end load is 1% of the input power. A cross-polar filter was not fitted.

The theoretical echoing area (σ_F) of the equivalent flat plate is:—

$$\sigma_F = 4{\cdot}8 \text{ m}^2$$

(Since the vertical height of the waveguide is less than half a wave-length, application of the simple geometric optics formula would not be expected to give a very accurate figure.)

The average measured value, using the back of the array as the equivalent flat plate and with the transmitter horizontally polarised is:—

$$\sigma_F = 5{\cdot}9 \text{ m}^2 \pm 0{\cdot}5 \text{ m}^2$$

The average value for the front of the array, again with the transmitter horizontally polarised is:—

Main beam	$\sigma = 6{\cdot}37 \text{ m}^2 \pm 0{\cdot}5 \text{ m}^2$
Side lobes at 38° off the normal	$\sigma = 3{\cdot}25 \text{ m}^2 \pm 0{\cdot}5 \text{ m}^2$

The re-radiation pattern of this array is shown in Fig. 2; the dotted line indicates the angular position of the main beam in the horizontal radiation pattern, at the measurement frequency (9420 MHz).

Vertically Polarised Array

(Shunt displaced slots in the broad wall, waveguide size 16.)

This array has an aperture distribution of $^1/_5 + ^4/_5 \, \mathrm{Cos}^2 \frac{\pi X}{a}$. The power reaching the end load is 2% of the input power.

The theoretical echoing area (σ_F) of the equivalent flat plate is:—

$$\sigma_F = 18{\cdot}25 \text{ m}^2$$

The average measured value, using the back of the array as the equivalent flat plate and with the transmitter vertically polarised is:—

$$\sigma_F = 18{\cdot}0 \text{ m}^2 \pm 0{\cdot}5 \text{ m}^2$$

The average values for the front of the array are as follows:—

Transmitter Vertically Polarised

Main beam	$\sigma = 3{\cdot}7 \text{ m}^2 \pm 0{\cdot}5 \text{ m}^2$
Side lobes at 38° off the normal	$\sigma = 5{\cdot}8 \text{ m}^2 \pm 0{\cdot}5 \text{ m}^2$

The re-radiation pattern of this array is shown in Fig. 3; the dotted line indicates the angular position of the main beam in the horizontal radiation pattern; at the measurement frequency (9420 MHz).

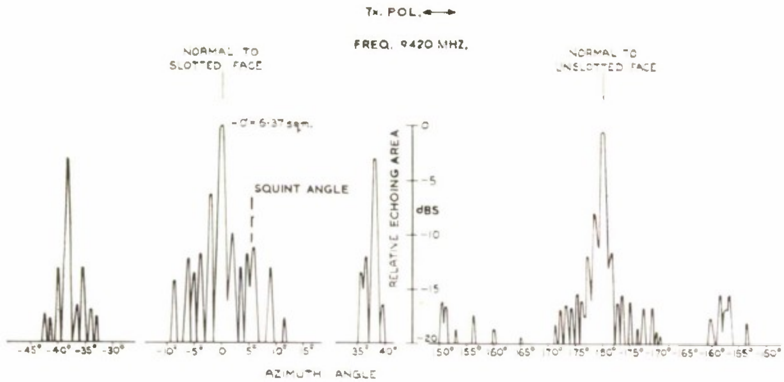

FIG. 2. Re-Radiation Pattern of 5' Horizontally Polarised Flat Array.

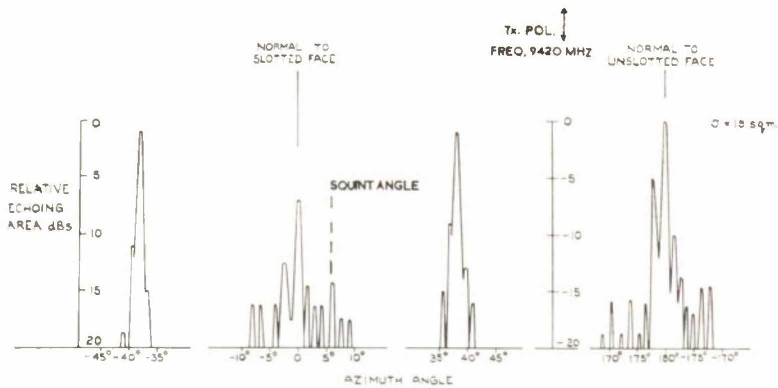

FIG. 3. Re-Radiation Pattern of 5' Vertically Polarised Flat Array.

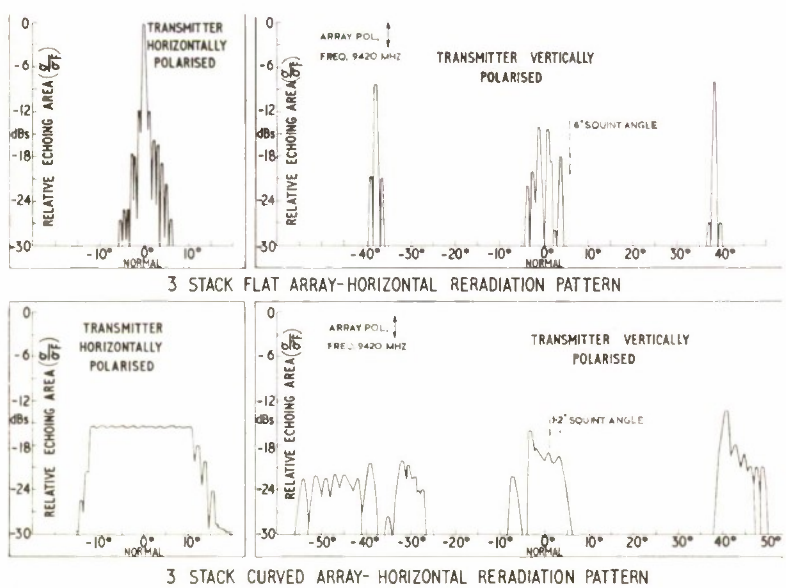

FIG. 4. 3 Stack Re-Radiation Patterns.

Monostatic Measurements on a Two Stack Flat Vertically Polarised Array

(58 Shunt displaced slots in the broad wall, waveguide size 16.)

This array has a horizontal aperture distribution of $\frac{1}{5} + \frac{4}{5}\ \mathrm{Cos}^2\frac{\pi x}{a}$ and a uniform vertical distribution, the power in the end loads being 2%.

The theoretical echoing area (σ_F) of the equivalent flat plate is:—

$$\sigma_F = 82{\cdot}45\ \mathrm{m}^2$$

The average measured values for the front of the array are:—

Transmitter Horizontally Polarised

Main beam $= 71\ \mathrm{m}^2 \pm 5\ \mathrm{m}^2$

Transmitted Vertically Polarised

Main beam $= 2{\cdot}8\ \mathrm{m}^2 \pm 0{\cdot}5\ \mathrm{m}^2$

Side lobes $= 17\ \mathrm{m}^2 \pm 2\ \mathrm{m}^2$

The re-radiation pattern is similar in character, though not in amplitude, to that shown for the three stack array Fig. 4.

Monostatic Measurements on a Three Stack Flat Vertically Polarised Array

The three stack array has the same distributions and power in the end loads as the two stack array.

The theoretical echoing area (σ_F) of the equivalent flat plate is:—

$$\sigma_F = 193{\cdot}2\ \mathrm{m}^2$$

The average measured values for the front of the array are as follows:—

Transmitter Vertically Polarised

Main beam $\sigma = 177\ \mathrm{m}^2 \pm 10\ \mathrm{m}^2$

Transmitted Vertically Polarised

Main beam $\sigma = 7\ \mathrm{m}^2 \pm 0{\cdot}5\ \mathrm{m}^2$

Side lobes $\sigma = 27\ \mathrm{m}^2 \pm 2\ \mathrm{m}^2$

The re-radiation patterns of this array, for both horizontal and vertical polarisations, are shown in Fig. 4.

The flat array measurements are summarized in Table 1.

TABLE 1

5 Ft. Flat Arrays—Echoing Areas

Array Description	*Transmitter Polarisation*	*σ_F (m²) Theoretical*	*σ_F (m²) Meas'd*	*Slotted Face Measured Value (m²)*	
				Main Beam	*Max. Side Lobes*
Single Horizontally Polarised	Horizontal	4·8	5·9	6·37	3·25
Single Vertically Polarised	Vertical	18·25	18·0	3·7	5·8
2 Stack Vertically Polarised	Vertical	82·45		2·8	17
2 Stack Vertically Polarised	Horizontal	82·45		71·0	
3 Stack Vertically Polarised	Vertical	193·2		7·0	27
3 Stack Vertically Polarised	Horizontal	193·2		177	

Bi-Static Measurements on a Three Stack Vertically Polarised Array

Transmitter Vertically Polarised

Bi-static measurements were made using a separate receiving antenna which was moved in 2° to 5° steps out to 55° from the transmitter, round a circle 350 ft. radius, the three stack array being at the centre of the circle. One measurement was also made at 80° from the transmitter. At each step a re-radiation pattern was recorded for one complete rotation of the three stack array. The maximum value from each pattern, normalised to the flat plate value was plotted against the appropriate receiver bearing in degrees. This is shown, in solid line, in the upper half of Fig. 5.

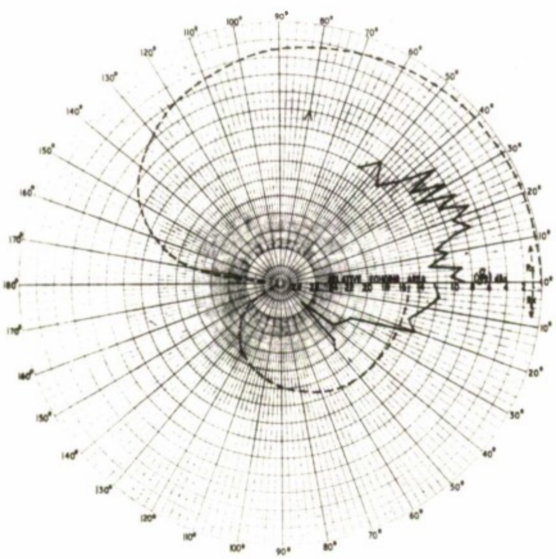

FIG. 5. Plot of Maximum Echoing Areas Extracted from Bi-static Re-Radiation Patterns, Transmitter fixed at 0°, Receiver moved in 2° to 5° steps at a radius of 350 ft. about the target. Transmitter freq. 9400 MHz.

Bi-static measurements were not made with the transmitter horizontally polarised because of the time-consuming nature of this type of experiment and because, as shown by previous measurements, the array behaved with this polarisation very much as if it were a flat plate. The maximum value of the echoing area at any point round the circle would therefore be close to the calculated value given by:—

$$\sigma\theta = \sigma \operatorname{Cos}^2 \frac{\theta}{2}$$

where θ = angle subtended, at the target antenna, between the transmitter and the receiver = twice the angle of rotation the target antenna.

σ = Target antenna echoing area at $\theta = 0°$.

$\sigma\theta$ = Echoing area at angle θ from transmitter.

The curve derived from the above formula, normalised to the flat plate value, is shown by the dashed line in the upper half of Fig. 5.

Comment on Flat Array Measurements

As can be seen from Figs. 2 to 4, all the flat arrays measured, have, with the transmitter polarised in the same sense as the array, a characteristic re-radiation pattern of a main lobe and two large side lobes. These side lobes which appear at an angle of ±38° from the normal to the array are 'reflection grating' lobes caused by the periodic discontinuity introduced by the constant pitch slots. (A row of nails spaced at the slot pitch produces the same shaped re-radiation pattern.) It has also been shown that, in the case of the horizontally polarised array, de-tuning the slots by covering the ends with metal foil so that they are no longer resonant at the transmitter frequency, reduces the side lobes considerably without materially affecting the magnitude of the main beam. Thus it would appear that the main beam is largely specular reflection.

A point of interest, at present unexplained, arises from a comparison of the echoing area, at normal incidence, of the single horizontally polarised array with the single vertically polarised array. Table 1 shows that, for the horizontally polarised array the echoing area of the slotted face is greater than either the theoretical or measured flat plate values, whilst for the vertically polarised array, the echoing area of the slotted face is considerably less than the flat plate value. Also, the horizontally polarised array although only half the area of the vertically polarised array has nearly twice the echoing area. The phenomenon appears to be associated with the type of slot rather than any resonant dimension of the waveguide since the echoing area of the unslotted face agrees reasonably well with the theoretical flat plate value. This suggests that, where reduction in echoing area is important, planar arrays of stacked waveguides should have shunt displaced slots rather than inclined edge slots.

The re-radiation patterns taken during the bi-static measurements were similar in character to the monostatic patterns; i.e. they exhibited a split main beam and two large side lobes at 38° on either side of the normal, the amplitudes, naturally, diminishing with increasing angle between transmitter and receiver. The maximum values measured at each station—the side lobes being greater in value than the main beam out to 25°—is shown, in solid line, on the upper half of Fig. 5.

In general, a stack of flat arrays will have the greatest echoing area when illuminated with r.f. energy which is cross-polarised or outside the pass-band of the slots and this will approximate to the theoretical flat plate value.

Monostatic Measurements on a Two Stack Curved Vertically Polarised Array

(71 Shunt displaced slots in the broad wall, waveguide size 16)

This array has a horizontal aperture distribution of $^1/_7 + {}^6/_7 \operatorname{Cos}^2 \frac{\pi x}{a}$ and a uniform vertical distribution.

The antenna is bent along its length into an arc of 3·5 m radius and the slot pitches are adjusted to restore the flat phase front.

The theoretical echoing area of a curved surface, in the direction of incidence when the length is greater than a few wavelengths and not appreciably less than the radius of curvature, is given by W. Spendley and R. V. Alred* as:—

$$\sigma = \frac{4\pi A^2}{\lambda^2} \Bigg/ \frac{2\iota^2}{R\lambda}$$

where 'A' = the projected area

'λ' = the free space wavelength

'ι' = the length of the surface

'R' = the radius of curvature

Using the above formula the theoretical echoing area of the two stack curved array is:—

$\sigma = 1{\cdot}9$ m^2

The average measured values were:—

Transmitter Horizontally Polarised

$= 2{\cdot}9$ m$^2 \pm 0{\cdot}5$ m^2

Transmitter Vertically Polarised

$$\left.\begin{array}{ll}\text{Main beam} & = 2{\cdot}3 \text{ m}^2 \\ \text{Side lobes} & = 2{\cdot}8 \text{ m}^2\end{array}\right\} \pm 0{\cdot}5 \text{ m}^2$$

The re-radiation pattern is similar in character to that shown for the three stack array. Fig. 4.

Monostatic Measurements on a Three Stack Curved Vertically Polarised Array

This array is similar in all respects to that described in the chapter entitled Monostatic Measurements on a Two Stack Vertically Polarised Curved Array except that it is three waveguides high instead of two.

The theoretical echoing area is:—

$\sigma = 4{\cdot}42$ m^2

The average measured values are:—

Transmitter Horizontally Polarised

$\sigma = 5{\cdot}6$ m$^2 \pm 0{\cdot}5$ m^2

Transmitter Vertically Polarised

Main beam $\sigma = 4{\cdot}3$ m$^2 \pm 0{\cdot}5$ m^2

Side lobes $\sigma = 9{\cdot}3$ m$^2 \pm 0{\cdot}5$ m^2

The re-radiation pattern of this array for both horizontal and vertical polarisation are shown in Fig. 4.

The curved array measurements are summarised in Table 2.

TABLE 2

5 Ft. Curved Array—Echoing Areas

Array Description	*Transmitter Polarisation*	*σ (m^2) Theoretical*	*Slotted Face Meas'd Values (m^2)*	
			Main Beam	*Side Lobe*
2 Stack Vertically Polarised	Vertical	1·9	2·3	2·8
2 Stack Vertically Polarised	Horizontal	1·9	2·9	—
3 Stack Vertically Polarised	Vertical	4·42	4·3	9·3
3 Stack Vertically Polarised	Horizontal	4·42	5·6	—

*Ref. *J.R.N.S.S.*, Vol. **3**, No. 6, November, 1948.

Bi-Static Measurements on a Three Stack Curved Vertically Polarised Array

Transmitter Vertically Polarised

Bi-static measurements were made as described for the flat array.

The calculated value with the transmitter horizontally polarised and the measured value with the transmitter vertically polarised; both normalised to the flat plate value, are shown plotted against receiver bearing in the lower half of Fig. 5.

Comment on Curved Array Measurements

Comparing the two stack and three stack curved arrays with the equivalent flat arrays, the transmitter being horizontally polarised, the echoing area of the two stack curved array is 14 dB lower than the flat array and the three stack curved array 15 dB lower than the three stack flat array (Fig. 4). Adversely the beamwidth of the curved array is about five times greater than that of the flat array at the -15 dB level. Thus the reduction of 15 dB in the echoing area produced by curving the array in one plane will reduce the maximum range of detection by 58% but increase the chance of detection at this reduced range. (The beamwidth of a flat surface with dimensions greater than a few wavelengths is dependent on aperture dimension and frequency. The beamwidth of a curved surface is independent of frequency and dependent only on the angle subtended by the curved surface at its centre of curvature and is approximately equal to that angle. For a doubly curved surface both beamwidth and echoing area are independent of frequency.)

With the transmitter vertically polarised the echoing area of the main beam is not significantly different from that of the flat array, but the maximum side lobe level is reduced by about 4·5 dB.

The bi-static measurements indicate that the wide angle scatter as the antenna rotates is also significantly reduced for a curved array (See Fig. 5 lower half, solid line.)

Description of the Curved Array

Fig. 6 shows a photograph of the three stack curved array used in the previously detailed experiments.

Each array is made from aluminium waveguide bent into a curve of 3·5 m radius and slotted as shown. The arrays are 48 wave-

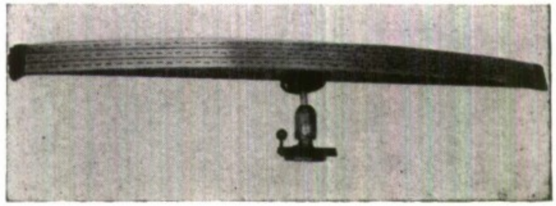

FIG. 6. 3 Stack Curved Array.

lengths long and the distribution used was $^1/_7 + {}^6/_7 \cos^2 \frac{\pi x}{a}$ which gives a computed maximum side lobe of -31 dB. The half power beamwidth is 1·7° and the power reaching the end load is 0·1% of the input power.

A straight linear array where the slots are equally pitched cannot be used to produce a beam at broadside because at the broadside frequency the slots are $\frac{\lambda g}{2}$ apart, the individual mismatches of the slots add up and the power lost due to reflection becomes unacceptable. It is necessary therefore to design a straight array with a minimum squint at one end of the frequency band of about $1\frac{1}{2}$ beamwidths from the normal to the array. Because the transverse polar pattern of a squinting array lies on a conical surface as distinct from a plane surface for a non-squinting array, there are bearing errors at elevations above, and depressions below the plane containing the array. These errors can be quite considerable in say a fan beam antenna with a large vertical beamwidth. The flat arrays considered here would have a minimum squint of 3° and a maximum of about 6° over the 3% frequency band. With the curved array, since the slot pitches are altered to compensate for the phase error introduced by the bend and are no longer equally pitched, it is possible to design the array to have the beam at broadside for the mid-band frequency. For the curved array the change in beam direction, relative to the normal, is $\pm$ 1·2° for a 3% frequency change. This reduction in squint gives about a 4 : 1 reduction in bearing error at elevations greater than 10°.

Also, again because the slots are not equally pitched, the magnitude of the off-axis grating lobes are also reduced by about 4 dB, the maximum amplitude—which occurs at an azimuth angle of 38° and an elevation angle of 20°—being -25 dB relative to the main beam at 0° elevation.

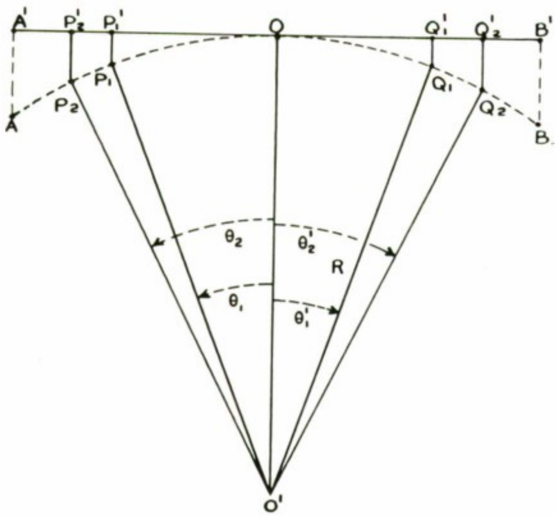

FIG. 7. Geometry of Curved Array Calculations.

Calculation of Slot Pitches

With reference to Fig. 7:—

Let P_1, P_2 . . . and Q_1, Q_2 . . . be slots in the array AB which is in the form of a circular arc of radius R.

Suppose there is a slot at O, the centre of the array, and suppose that $\overset{\frown}{AO} - \frac{2\pi}{\lambda g} = K$ (A being the feed end of the array).

There is an additional phase change of π between consecutive slots because of the slot design therefore for uniform phase along the line A'B' (y=O) we must have:—

$$\frac{2\pi}{\lambda g}AP_2 + \frac{2\pi}{\lambda_o}P_2P_2' + 2\pi = \frac{2\pi}{\lambda g}\overset{\frown}{AP}_1 + \frac{2\pi}{\lambda_o}$$
$$P_1P_1' + \pi = \frac{2\pi}{\lambda g}\overset{\frown}{AO}$$

i.e. with

$$\widehat{OO'P}_1 = \theta_1;\ \widehat{OO'P}_2 = \theta_2 \ etc.$$

$$\frac{2\pi}{\lambda g}\left\{\overset{\frown}{AO} - R\theta_1\right\} + \frac{2\pi}{\lambda_o}$$
$$R(1-\text{Cos }\theta_1) + \pi = \frac{2\pi}{\lambda g}\overset{\frown}{AO}$$

i.e.

$$\frac{2\pi}{\lambda g}R\theta_1 - \frac{2\pi}{\lambda_o}R(1-\text{Cos }\theta_1) = \pi$$

or

$$\frac{R\theta_1}{\lambda g} - \frac{R(1-\text{Cos }\theta_1)}{\lambda_o} = \tfrac{1}{2}$$

and

$$\frac{2\pi}{\lambda g}\left\{\overset{\frown}{AO} - R\theta_2\right\} + \frac{2\pi}{\lambda_o}$$
$$R(1-\text{Cos }\theta_2) + 2\pi = \frac{2\pi}{\lambda g}\overset{\frown}{AO}$$

$\therefore$

$$\frac{R\theta_2}{\lambda g} - \frac{R(1-\text{Cos }\theta_2)}{\lambda_o} = 1$$

Similarly

$$\frac{R\theta m}{\lambda g} - \frac{R(1-\text{Cos }\theta m)}{\lambda_o} = \frac{m}{2}$$

===========

This formula establishes the positions of the slots between the feed end and the centre of the array. For the slots in the other half of the array we proceed as follows:—

$$\frac{2\pi}{\lambda g}\overset{\frown}{AO} + 2\pi = \frac{2\pi}{\lambda g}\overset{\frown}{AQz_1} + \frac{2\pi}{\lambda_o}$$
$$Q_1Q_1' + \pi = \frac{2\pi}{\lambda g}AQ_2 + \frac{2\pi}{\lambda_o}Q_2Q_2'$$

$\therefore$ if

$$\widehat{OO'Q}_1 = \theta_1{}^1;\ \widehat{OO'Q}_2 = \theta_2 \ etc.$$

$$\frac{2\pi}{\lambda g}\left\{\overset{\frown}{AO} + \overset{\frown}{OQ}_1\right\} + \frac{2\pi}{\lambda_o}$$
$$Q_1Q_1' + \pi = \frac{2\pi}{\lambda g}\overset{\frown}{AO} + 2\pi$$

$\therefore$

$$\frac{2\pi}{\lambda g}R\theta_1' + \frac{2\pi}{\lambda_o}R(1-\text{Cos }\theta_1') = \pi$$

$\therefore$

$$\frac{R\theta_1'}{\lambda g} + \frac{R(1-\text{Cos }\theta_1')}{\lambda_o} = \tfrac{1}{2}$$

and in general for this half of the array:—

$$\frac{R\theta' m}{\lambda g} + \frac{R(1-\text{Cos }\theta' m)}{\lambda_o} = \frac{m}{2}$$

===========

Having established the positions of all the slots, with 'x' and 'y' co-ordinates for each slot, the amplitudes and hence the coupling factors for the slots can be calculated.

In the present design the amplitude distribution was chosen to be:—

$$A(x) = {}^1/_7 + {}^6/_7 \text{ Cos}^2 \frac{\pi x}{a}$$

where 'a' is the total width of the aperture.

The radiation pattern G (ϕ) is then given by:—

$$G(\phi) = \sum_{1}^{N} A_{\tau}\, e^{j\frac{2\pi}{\lambda_0}(x_{\tau}\,\mathrm{Sin}\,\theta - y_{\tau}\,\mathrm{Cos}\,\theta)} \cdot e^{J\psi_{\tau}}$$

where N=Total number of slots

$$\psi = \begin{cases} \dfrac{2\pi}{\lambda g} R\theta m - m\pi \text{ for slot Pm} \\ m\pi - \dfrac{2\pi}{\lambda g} R\theta m \text{ for slot Qm} \end{cases}$$

The τth slot having co-ordinates (x_{τ}, y_{τ}) and amplitude A_{τ}

N.B. The slot at 'O' where A=1, x=y=O, θ=O must not be forgotten in the summation.

Radiation Pattern and V.S.W.R. Measurements

Radiation patterns were measured on a 500ft. site, $\frac{2D^2}{\lambda o}$, over a frequency band of 9000 MHz to 9800 MHz. The measured horizontal patterns at 9000 MHz, 9400 MHz, 9600 MHz and 9800 MHz are shown in Fig. 8. It will be noted that the near-in side lobe level is greater than the theoretical value, being −24 dB at 9000 MHz and further deteriorating with increasing frequency. This was assumed to be due to a phase and amplitude error across the array. The latter was subsequently confirmed by a plot of the actual amplitude distribution. The plot shows a marked distortion of the amplitude pattern on the load side of the centre line where the slot pitches begin to cramp up, and is almost certainly due to increased mutual coupling between slots. This could be corrected in any future design.

The measured V.S.W.R. of the two stack array including the 3 dB power divider used to feed it is shown in Fig. 10. Broadside is at 9650 MHz.

Conclusion

The experiments detailed above show that antennae composed of flat linear arrays, with dimensions greater than a few wavelengths, when illuminated with r.f. energy, the frequency of which is inside the pass-band but polarised at 90° to the array polarisation, have an echoing area and re-radiation pattern comparable with the same size flat plate and agree reasonably well with the theorctical values. This should also

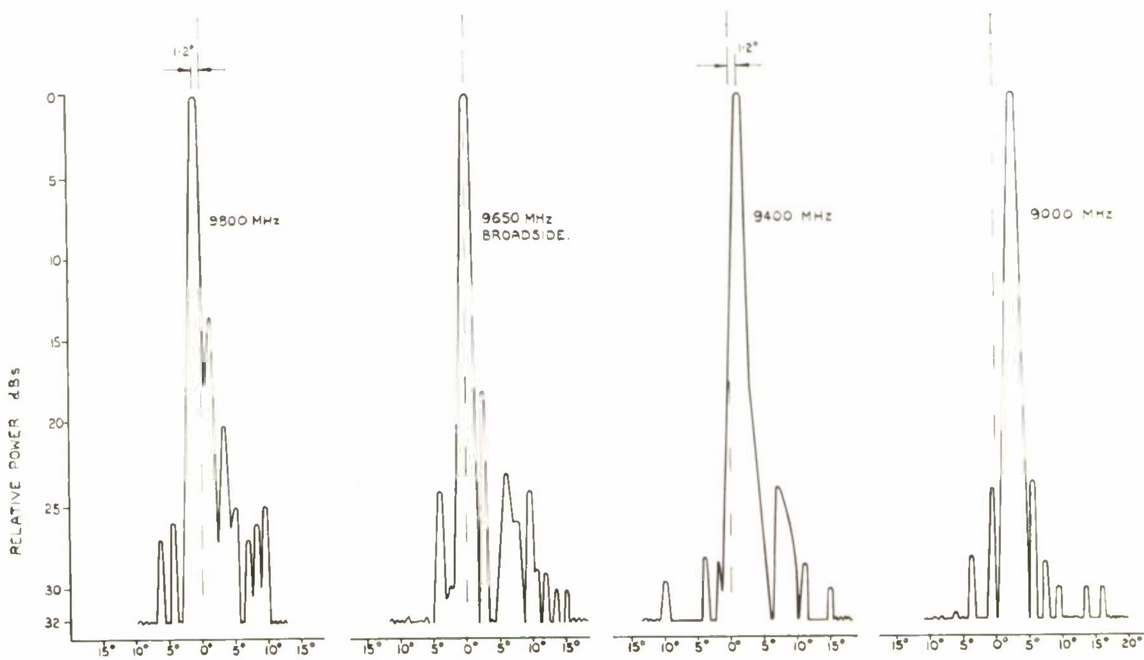

FIG. 8. 2 Stack Curved Array — Horizontal Radiation Patterns.

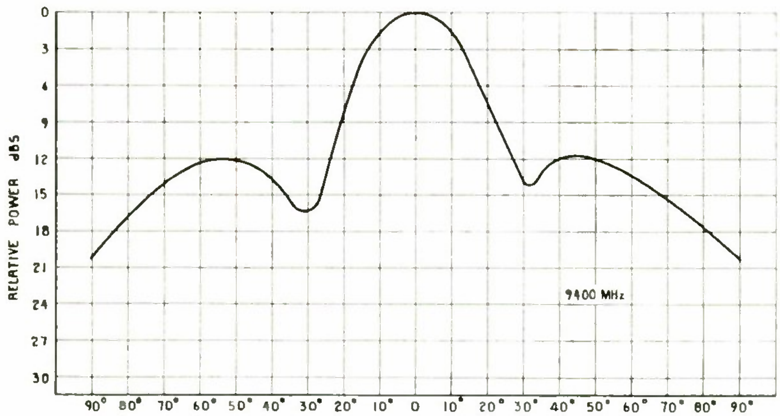

FIG. 9. 2 Stack Curved Array—
—Vertical Radiation Pattern.

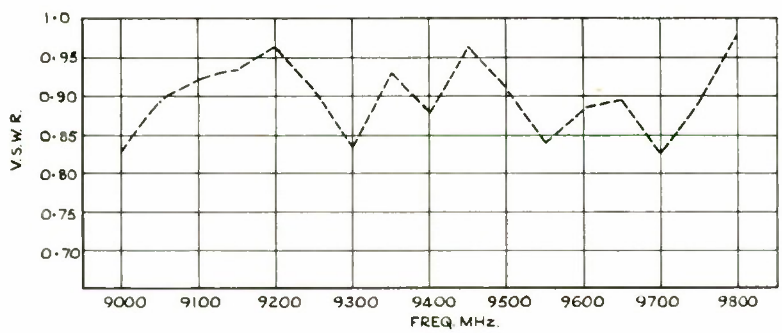

FIG. 10. 2 Stack Curved Array VSWR at input to 3dB Power Divider.

be the case for lower frequencies, outside the pass-band, whatever the polarisation, but is not necessarily true for higher frequencies. Inside the pass-band with the transmitter polarised in the same sense as the array, the main beam echoing area is less than the flat plate value, but the re-radiation patterns show large reflection-grating lobes which are comparable with or greater in magnitude than the main lobe.

Bending the antenna, in one plane, into quite a shallow curve will significantly reduce the echoing area *whatever the polarisation or frequency* of the illuminating radar, provided that the antenna dimensions are always greater than a few wavelengths. For an antenna 1·5 m long a reduction of at least 15 dB in echoing area should be obtainable at 'X' band. The re-radiated beamwidth in the plane of the curve is independent of frequency and is approximately equal to the angle subtended by the curved surface at its centre of curvature.

By bending the antenna in both planes a further reduction in echoing area could be achieved; both re-radiation beamwidth and echoing area would then be independent of frequency and would be constant for given aperture dimensions and radii of curvature.

Two further advantages of curved arrays are firstly the ability to work through broadside, thus reducing bearing errors at high angles of elevation; and secondly a reduction in the off axis grating lobe level.

Acknowledgment The author is indebted to Mrs. E. French for the calculations on slot pitches and to Mr. J. E. McDougall and Mr. D. Morris for the, often difficult, field measurements involved. Also to Dr. J. Croney, Mr. J. H. Boon and Mr. G. J. Colley for helpful discussion and criticism.

NEW 100W SOLID-STATE TRANSMITTER AND RECEIVER

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The Marconi Company Limited

J. A. Gould was born at Bude in 1927 and educated at the Nautical College, Pangbourne and Trinity Hall, Cambridge where he obtained an honours degree in mechanical sciences. He entered The Marconi Company in 1949 as a graduate apprentice and then joined the Maritime Development Group where he was associated with the development of h.f. communications receivers and transmitters for use on merchant ships. He subsequently led a team of engineers developing a frequency synthesizer. For the past four years he has been leader of a development group dealing with naval communications equipment.

Abstract

The equipment described has been developed to meet a demand for a low-cost solid-state transmitter and receiver primarily for naval use, compatible for most modes of transmission with more sophisticated fully synthesized and automatically-tuned equipments, but at a considerably lower cost than previously possible. This has been achieved by the use of a frequency counting and correcting system which gives an overall stability and setting accuracy of a few Hz with the added advantage of continuous tuning, combined with the application of value engineering principles throughout the development.

Introduction

The increasing use of single sideband for h.f. communication in recent years has created a demand for a high order of frequency stability for both transmitters and receivers, combined with the ability to change frequency rapidly and precisely over the whole h.f. band.

To meet this demand several sophisticated equipments have been developed, the majority of which employ frequency synthesis in some form or another in order to produce any required frequency, usually in discrete steps, with the stability of a single highly-stable master oscillator. Often a single external oscillator is used to control a number of transmitters or receivers. Examples of such equipments are the MST range of transmitters and receivers for fixed stations and the N3000 series[1] designed primarily for naval use.

These equipments, employing full frequency synthesis down to 100Hz steps combined with automatic tuning, are, of necessity, relatively expensive. While this can be justified for many fixed stations and for large naval vessels such as aircraft carriers, which are used as mobile communications centres, there is also a requirement for a less costly equipment for use in smaller ships and other mobile applications.

Small naval vessels need equipment compatible with that in the major ships and shore stations, still retaining a sufficiently high order of frequency stability for s.s.b. voice communications or single channel v.f.t., without the need for a.f.c. at the receiver, but with more emphasis on reduced cost and size. However, certain features can be sacrificed without detriment to the performance, *e.g.* manual in place of automatic tuning, single-sideband facility in place of independent sideband. Also a considerable cost saving can be achieved by building the antenna matching circuits into the transmitter thus eliminating the need for a separate tuner at the base of the antenna. This does, of course, put a restriction on the siting of the equipment which must then be placed within about 20ft. of the antenna, and coupled to it via a suitable trunk or large coaxial cable.

The 'Aries' 100W transmitter and 'Argo' general purpose receiver have been developed primarily to meet this requirement.

Equipment Features

The principal feature of these equipments is the unique frequency counting and correcting system which, at a small proportion of the cost of full frequency synthesis, provides continuous tuning over the entire h.f. band with a setting accuracy of 1·0Hz and frequency stability of a few Hz.

The transmitter employs a drift cancelling loop for the selection of 1·0MHz steps (with the full stability of the internal standard) in conjunction with an interpolating oscillator tuneable over a 1·0MHz band. An output from this oscillator is applied to a counting and correcting system which provides a digital display of the transmitter frequency down to the nearest 1·0Hz. By comparing the last three figures of the count with figures set up on three digit selector switches, the necessary correction is applied to the oscillator to maintain it within ± 2Hz of the required frequency.

A similar system is employed in the receiver but in this case the drift cancelling loop provides 100kHz steps and the interpolating oscillator tunes over a band of 100kHz. The conventional receiver tuning scale is retained and this in itself provides a resolution of about 50Hz on the h.f. bands, which is enhanced by an additional digital display of the last three figures only.

This system enables the receiver to be used in one of three modes.

(a) As a continuous search receiver over a wide band using a single tuning control.

(b) To provide a more accurate continuous search over any 100kHz band above 1·6MHz, with an incremental tuning scale reading to within 50Hz, plus a digital read-out down to the nearest 1·0Hz.

(c) To pull the receiver automatically within a few Hz of the frequency set by the digit selector switches, and to hold that frequency for long periods without readjustment. The setting of the selector switches can be either to a frequency already known or determined by search procedures as *(b)*.

Many of the following additional features are of particular importance for naval shipborne equipments where transmitters and receivers must operate in close proximity.

(a) Suitability for a wide range of modes of operation, A1, A2H, A3A, A3J (upper or lower sideband).

(b) A low level of wideband noise radiation from the transmitter to avoid interference with receivers having antennas close to that of the transmitter.

(c) Good front-end protection in the receiver to minimize the effects of high-level signals, separated from the wanted frequency by only a few per cent.

(d) Provision for simplex operation with transmitter and receiver using the same antenna.

(e) Ability to tune into a wide range of antennas from short whips to medium length wires.

(f) Ability to operate over a wide range of ambient temperatures (0°C to +55°C), humid tropical conditions and severe conditions of shock and vibration.

(g) Robust bench-mounting cabinets with capability of stacking two or three receivers or one transmitter and one receiver.

(h) Balanced antenna input to receiver, to enable a number of receivers to be connected in series on a common antenna feeder.

(i) A high degree of reliability and ease of maintenance, by the use of all solid-state devices, digital integrated circuits and modular construction.

(j) Built-in frequency standard in both transmitter and receiver with provision for feeding one equipment from the oscillator in another or from a common external standard.

The Transmitter

The transmitter comprises two runner mounted units in a robust cabinet intended for bench mounting on suitable resilient mounts. Fig. 1.

Fig. 1. 'Aries', 100W h.f. transmitter type H1030

The lower unit is the drive which contains the sideband generating and frequency determining circuits and provides a low level output to feed into the solid-state linear power amplifier.

The amplifier is mounted in the upper unit and has a power output of 100W p.e.p. into 50 ohms. Also fitted in the upper unit are the antenna matching circuits which enable the amplifier output to be matched into the wide range of impedance presented by ships' antennas.

Both units are completely self contained, with integral a.c. power supplies, and therefore may be used independently or in different configurations.

The frequency range of the complete transmitter is from 425kHz to 17MHz, but because the drive unit can be used with other equipments its frequency range covers 240kHz to 1·0MHz and 1·5MHz to 30MHz.

Drive Unit

Sideband generator

After volume compression and limiting, the audio input is applied to a balanced modulator, the output of which passes through a sideband filter to produce an upper-sideband suppressed-carrier signal at 2MHz. This 2MHz signal is then mixed with either 5MHz, for an upper sideband output, or with 9MHz, for lower sideband output, to produce a second intermediate frequency of 7MHz. Fig. 2.

Provision is made for fitting a second sideband generator channel for i.s.b. working, in which mode the outputs are combined at 7MHz in the frequency translator.

For A3A or A3H operation, a reinserted carrier is obtained by reinjecting the 2MHz signal at a controlled level after the sideband filter. Keyed carrier for A1 operation is also available via this route.

As an alternative for A1 operation, facilities are included to enable a 1·0kHz tone, derived by frequency division from the internal 1·0MHz standard, to be keyed and injected into the audio channel.

Frequency translator

This assembly contains four mixers and associated filters which, together with the 40·5MHz to 69·5MHz stepped oscillator, comprise a drift cancelling loop for selection of the 1·0MHz increments of output frequency. The system is based on the generation of harmonics of 1·0MHz in the range 5MHz to 34MHz, the required harmonic being selected by mixing with the stepped oscillator and passing through a fixed filter at 35·5MHz.

After further combining with the 2MHz to 3MHz interpolating oscillator and the 7MHz intelligence bearing signal, a final i.f. of 39·5MHz to 40·5MHz is produced which is then mixed with the second output from the stepped oscillator, in such a way that any

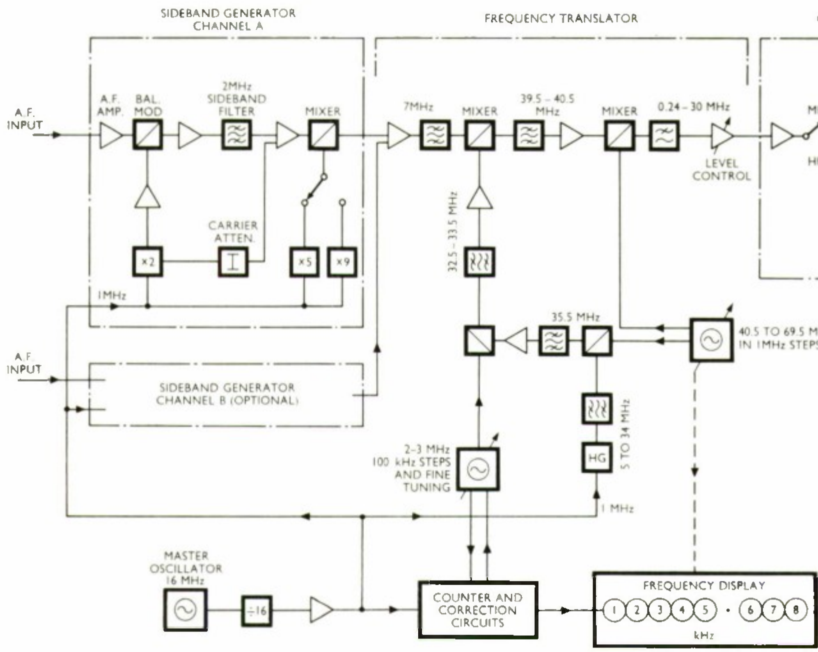

Fig. 2. Simplified block diagram of H1030 drive unit

small variations in the frequency of this oscillator are cancelled out and do not affect the final output frequency. The stability of the output frequency thus depends only on the stability of the 16MHz standard, from which the 1·0MHz harmonics are derived, and of the 2MHz to 3MHz interpolating oscillator.

The final frequency thus produced then passes through a low-pass filter followed by an amplifier, the gain of which may be varied by the r.f. level control on the front panel.

Tuning unit

This unit amplifies the final output to a nominal 100mW and incorporates tuneable filters to reduce the level of noise at ±5% or more off-tune to a sufficiently low level to render the equipment suitable for co-sited transmitter receiver installations. This is achieved by a two stage wideband amplifier, with a bandpass pair of circuits between the two stages and a single tuned circuit after the final amplifier.

The h.f. band from 1·5MHz to 30MHz is covered in four ranges, the appropriate inductors being switched into circuit by relays controlled from the MHz selector switch. Each set of inductors is continuously tuned over the range by a three-gang variable capacitor, operated by the " tuning " control on the front panel. Below 1·0MHz an untuned low-pass filter is employed.

2MHz to 3MHz oscillator

This is a precision L-C oscillator tuneable over the range 2MHz to 3MHz to provide interpolation between the 1·0MHz steps. It is designed to have a low temperature coefficient and excellent short-term stability, particularly under conditions of vibration and shock. The principal frequency determining elements are a precision ceramic inductor with fired-on silver conductor, a set of controlled temperature-coefficient capacitors, selected by the 100kHz switch, and a variable capacitor for continuous tuning over each 100kHz, controlled by the " fine tune " control on the front panel.

Frequency display and error correction unit

This unit performs two main functions.

(a) To provide a digital frequency display down to the nearest 1·0Hz to indicate the transmitter frequency.

(*b*) To detect any error in the frequency of the 2MHz to 3MHz oscillator and apply and maintain any correction necessary.

An output from the 2MHz to 3MHz oscillator is fed to the counter, which feeds the last six digits of the display to indicate the output frequency down to the nearest 1·0Hz. The remaining two digits indicating MHz are controlled from the MHz selector switch. Adjacent to the display are three digit selector switches. These are set to correspond with the last three digits of the required frequency.

On completion of each count (1·0s) and display (0·5s) the correction system operates in the following manner.

A standard signal is fed into the main counter for a period necessary to make the last three digits coincide with those set on the switches. This period is therefore proportional to the frequency error. During this period the same signal is fed into a separate error counter which therefore clocks up an amount proportional to the error. The output from this counter is then applied to a digital to analogue converter and then, via a storage element, to a varactor controlling the oscillator frequency.

The procedure for setting up any frequency is as follows:

(1) Set MHz and 100kHz switches as required.

(2) Depress " tune " switch to speed up the count to 1/10s and immobilize the correcting system.

(3) Adjust " fine tune " control until the counter indicates within about 100Hz of correct frequency.

(4) Release " tune " switch when the counter reverts to the normal one second count time and the correction system operates. After each successive count a correction will be applied and the indicated frequency will be seen to approach the required setting. This will be reached within $\pm 1{\cdot}0$Hz after no more than three or four counts and be maintained for long periods.

The maximum correction which can be applied by this system is approximately ± 500Hz. The 2MHz to 3MHz oscillator is designed to keep well within this range over periods of several days and with ambient temperature changes up to at least 20°C, so no further retuning should normally be necessary. However, a lamp is fitted to indicate when more than about 400Hz correction is being applied as a warning that retuning is desirable.

Master oscillator

This comprises a 16MHz BT cut crystal in a T05 can, maintained at a constant temperature around +75°C by means of a proportional control oven, contained in a small sealed can together with the crystal oscillator and oven control circuits.

The oscillator is followed by a buffer amplifier and 16 to 1 divider to produce the basic 1·0MHz for control of the counter time base etc., with a stability of better than ± 1 part in 10^7 over the full ambient temperature range of 0°C to +55°C.

Provision is also made for an external 1·0MHz standard to be fed in, or for the internally derived 1·0MHz to be fed out to another associated transmitter or receiver.

The oscillator and associated circuitry, together with the system control circuitry, are contained on a plug-in printed circuit board. Solid-state switching is used extensively for system control to minimize mechanical switching and improve stability.

Drive unit accessibility is shown in Fig. 3.

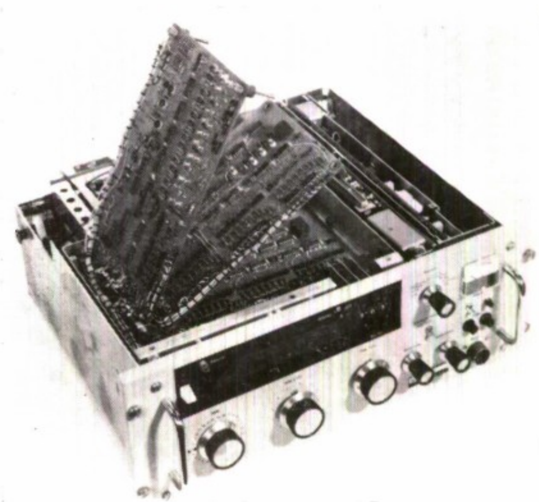

Fig. 3. Drive unit showing accessibility

Power supplies

The equipment is designed to operate from 45Hz to 65Hz, or 400Hz, single phase a.c. mains from 110 to 125V and 200 to 240V.

A modular power supply unit is employed to produce a basic 30V d.c. stabilized output which directly supplies the higher power stages. Miscellaneous other voltages, *e.g.* 200V for the indicator tubes, 12V for the crystal oven and digital to analogue converter, and 5V for the integrated circuits are derived from the 30V basic output by means of a converter circuit.

fitted to the heat-sink cuts off the supply to the amplifier if excessive temperatures are reached, *e.g.* in the event of a fan failure or air filter blockage.

Forward and reverse power detectors are connected into the 50 ohm output. These feed the front panel meters to provide an indication of tune condition and also feed a signal back

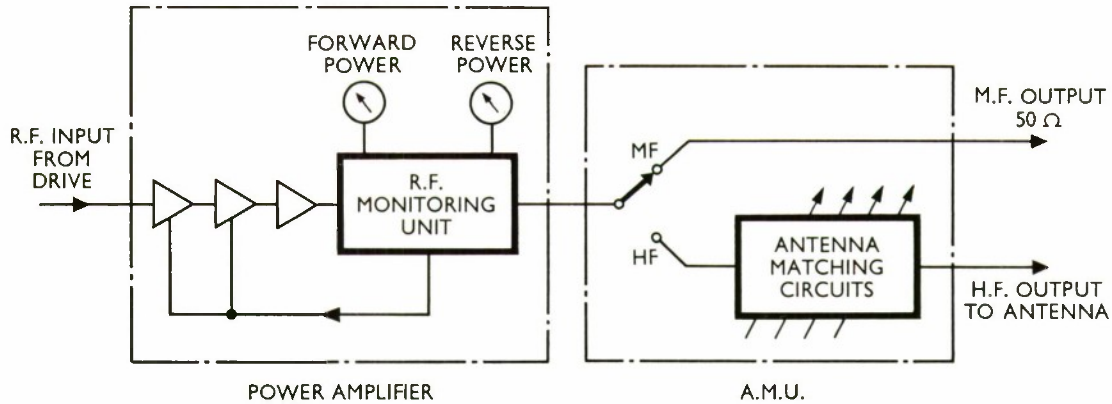

Fig. 4. Simplified block diagram of power amplifier and A.M.U.

Power Amplifier and Antenna Matching Unit

Power amplifier

The power amplifier comprises a three stage wideband linear amplifier providing 30dB gain over the frequency range of 400kHz to 17MHz. Fig. 4.

The first two stages each consists of two transistors in a push-pull configuration and the final stage 32 transistors in a push-pull parallel combination which develops 100W p.e.p. into 50 ohms.

With the present state of the art, the method of using a large number of low cost transistors, as opposed to perhaps two to four very expensive devices, presents the most economical approach to the problem of achieving this order of power output with the required linearity. It has the added advantage of incorporating ample reserve power capability and thus being more immune to damage from mismatch or overload conditions.

The whole amplifier is mounted on a finned heat-sink cooled by air blown from the fan in the top of the cabinet, enabling the amplifier to run continuously in ambient temperature up to +55°C outside the cabinet. A thermostat

to cut-off the early stages of the amplifier in the event of excessive reverse power.

Antenna matching unit

This is designed to match from the 50 ohm amplifier output into a wide range of antennas such as are likely to be encountered on ships, including up to 20ft. of trunking between transmitter terminal and the base of the antenna.

The circuit may be switched into either a "π" or "L" section filter according to antenna frequency. When employed as a π section, it comprises a variable inductor with fixed steps of capacitance on the input side and fixed steps plus a variable capacitor on the output. When used as an "L" section, mainly for the lower frequencies, the variable capacitor is transferred to the input side, and an additional loading inductor may be switched in series with the variable inductor.

Antenna changeover facilities are provided to enable a common antenna to be used for both transmitter and receiver.

Power supplies

The power supply unit for the amplifier is also designed to operate from 45Hz to 65Hz, or

400Hz, single phase a.c. mains from 110 to 125V and 200 to 240V, and in order to achieve high efficiency with minimum size, a switching type of stabilizer is employed to produce 30V d.c., capable of supplying up to 11A.

The Receiver

The design is a modified version of the Eddystone Model 958, which is a solid-state general purpose receiver with the wide frequency coverage of 10kHz to 30MHz, and which has been described in detail in a previous article.[2] Fig. 5.

Fig. 5. 'Argo' receiver type H2310

This receiver having been designed with maritime applications in mind, already includes many features making it suitable for naval use, notably a good degree of front-end protection and the ability to withstand high-level signals without damage.

For certain v.f.t. systems an even greater frequency stability and setting accuracy is required, so changes have been incorporated to modify these characteristics on the h.f. ranges, which also enhance the performance on s.s.b.

The receiver employs a drift cancelling loop on the h.f. ranges for selection of 100kHz steps which are locked to the internal master oscillator. Interpolation between these steps is provided by an oscillator continuously tuned between 550kHz and 650kHz. This oscillator is the main factor controlling the overall frequency stability and setting accuracy which are of the order of 200Hz.

In order to achieve a performance comparable with the transmitter a counting and correcting system has been added, similar to that used on the transmitter drive, which operates on the interpolating oscillator in such a way as to hold its frequency to within ± 2Hz of that set up on three digit selector switches. This counter also provides a digital read-out of the last three figures down to the nearest 1·0Hz, thus giving the required setting accuracy.

Some constructional changes have also been made. In order to accommodate the additional circuitry the panel height was increased from 5·25in. to 7in. and the styling modified to line up with the transmitter. The unit is now mounted on runners in a cabinet of similar design to the transmitter and suitable for stacking two or three receivers, or transmitter and receiver together.

Conclusions

The high performance to cost ratio required has been achieved in this design by the use of new techniques and by the application of value engineering principles throughout the development.

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[2] Ford, D. W. "Solid-state general purpose receiver —10kHz to 30MHz", *Point-to-Point Telecommunications*", **13**, 1 (January 1969).

A PARTIALLY-COHERENT SIGNAL PROCESSOR FOR CERTAIN TYPES OF ECHO LOCATION SYSTEMS

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Dr. Ralph Benjamin joined ASE (now ASWE) in 1944 from Imperial College. He has contributed to a wide range of that establishment's activities and published well over 200 technical reports. However his main field was air defence and aircraft control radar, action information systems, automation systems, and computers. He was made a special-merit SPSO in 1955 and a special-merit DCSO in 1960.

When a Deputy Chief Scientist and Head of Research at ASWE he wrote a book on Resolution Modulation on Signal Processing which gained him his doctor's degree from London University.

In 1964 he was appointed Head of AUWE. He has recently qualified as an RN diver.

Introduction

Many echo-detection systems are associated with target "highlight" patterns, "clutter" or " Reverberation " distributions and interference environments whose nature can be specified in advance. It may then be possible to devise modulation patterns matched to this situation; combined coherent, non-coherent and logical signal-processing systems of relatively modest cost and complexity may then become acceptable substitutes for a theoretical optimum detector. One example of such a system is briefly described.

" Bursts " of Pulses with Non-Coherent Processing

In many communications or detection systems, a single signal pulse may have a moderate margin over the mean " noise " level, but not sufficient to achieve an adequately low probability of losing a signal or, conversely, of mis-identifying a noise pulse as a signal. An increase in signal power may not be feasible, due to limitations to the peak power which available components—or the propagating medium—can support. Extra energy could however be used by spreading power of the given magnitude and bandwidth over a longer time. If the stability of the propagation path permits, consecutive signal samples may then be brought into time and phase coincidence, in a " coherent detector ", whilst leaving random noise—or the echo returns from distributed scatterers—spread

over the full range dimension. The output of this device therefore concentrates the wanted received signal energy in a shorter time interval, just as if the transmitter modulation had been of shorter duration but higher peak power.

As already implied, this technique is not practicable if the propagation path is too unstable. Moreover, it is of little help if the signal channel is subject to significant interference of fluctuating amplitude. Under these conditions it is better (as well as simpler) to represent each information element of a signal by a short " burst " of pulses, to be detected separately and combined in a suitable non-coherent logical manner. If each message (in a signalling system) or target echo (in an echo-type object location system) consists of a group of highlights, it would often be expedient for the pulses, within the burst, to be spaced by more than the total duration of the message (or group of associated highlights). Furthermore, for convenient unambiguous identification and timing of the members of a burst of transmitted pulses, it would be convenient if the interpulse interval I were linearly modulated (positively or negatively) with increasing time t from the start of transmission (i.e. $I=I_0+kt$). (See Figs. 1a and 1b.)

Since the Doppler effect is a linear expansion or compression of the time axis, k, the slope of the linear variation of *time* between pulses with respect to *time* in the total modulation pattern, would be immune to any Doppler effect. Hence a recognition system matched to this slope would be " Doppler-invariant ". Thus, for instance, the interval between transmitted signal pulses, in a burst, might be reduced by 1% from one to the next. Hence, in an underwater acoustic system, the time compression due to a 30 kn Doppler velocity (1% of the speed of sound in water) would produce an echo pattern matching the spacings sought, but with an apparent range displacement equivalent to two inter-pulse spacings.

The time relations within the burst of pulses, and the tolerances with which these relations are measured on reception, would be so chosen that a Doppler shift (in the example) of p% —where p is an integer—would give full output at an apparent range displacement of p pulse spacings (*i.e.* pI), and zero output at a range displacement of $(p\pm1)I$. However, any Doppler shift intermediate between p% and $(P-1)$% would cause the output to be shared

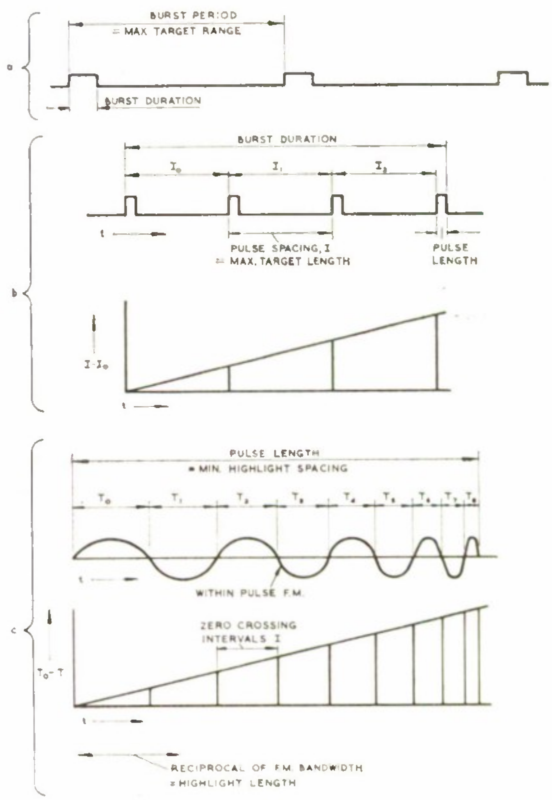

FIG. 1. Timing Relationships

pro-rata between the " range positions ", displaced by pI and $(p-1)I$.

In practice, it might be convenient to record the amplitude and timing of received pulses, exceeding a suitable (fixed or variable) amplitude threshold, in a computer-type core store; and to use computer-type logic to search this store for appropriate time—and amplitude distributions. Thus one stage of non-coherent, logical processing might identify, in order of decreasing amplitude, groups of n signal pulses (n≡number of pulses per burst) whose relative timing and amplitude fluctuation marks them as characteristic of the returns from a signal highlight. A further stage of processing would then confirm that the number, relative timing and amplitude pattern of a group of such highlights is representative of the type of message structure—or target echo pattern—being sought.

Coherent Pulse Compression Followed by Logical Processing

For detection against a background of Gaussian noise, it is sufficient if the constituent signal pulses are no longer than the minimum interval between signal highlights which require to be separately resolved. However, in an echo-location system, detection may well be limited by reverberation or clutter from a continuous mass of individually small scatterers. In that case, it would be desirable to restrict the effective range resolution to the length of the wanted individual target highlights. In order to gain adequate pulse energy, pulses of the bandwidth defined by this range-resolution may however be spread to cover the interval between signal highlights. They can then be recompressed by a coherent detector, as mentioned (in a different context) at the beginning of this note.

This coherent process can be made "Doppler-invariant", like the non-coherent one mentioned above, by varying the periodic time T (between zero-crossings) of the waveform linearly with total time t from the start of the waveform t (i.e. $T=T_0+Kt$). See Fig. 1c. In this case, however, the apparent range displacement, due to Doppler time compression would be practically insignificant.

At the output to the coherent detector, we can then apply a suitable combination of lower (and possibly upper) amplitude limits, together with continuous peak selection over a moving range "window" equivalent to the minimum spacing between highlights required to be resolved.

The overall scheme, resulting from these proposals, is illustrated in block-schematic form in Fig. 2.

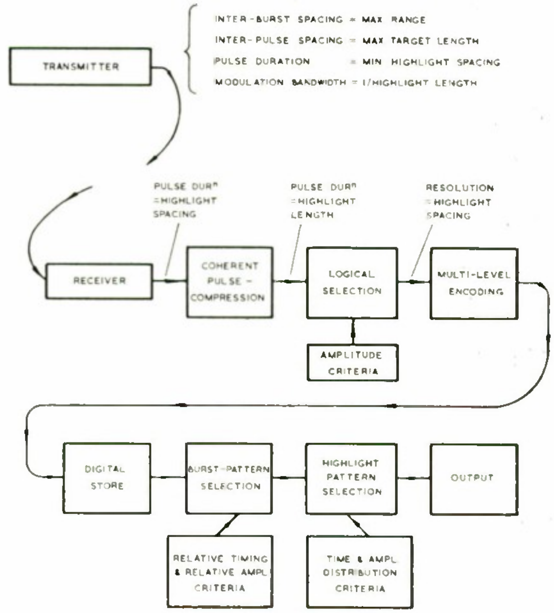

FIG 2. Overall Schematic Diagram

Cost Considerations

It will be noted that the peak input rate to the computer-type non-coherent processor is reduced in the ratio of highlight length to required resolvable highlight spacing. The mean input rate is of course further reduced in proportion to the number of potential inter-highlight intervals which are not in fact filled by target highlights:

(Total number of signal samples per burst)= (number of targets "visible") (number of resolved highlights per target) (number of pulses per transmission "burst"). Thus the through-put capacity—and hence the cost of the post-detection logical processor—should not need to be very large. (Indeed, many alerting, tracking or homing systems might well restrict themselves to, say, the first—or the first m—validated targets in a given range bracket, azimuthal beam and inter-burst interval.)

The complexity of the pre-detection coherent processor, and the criticality of its tolerances, are of course proportional to its pulse-compression ratio; (*i.e.* its processing gain). Hence the cost reduction ratio due to the proposed system, may be roughly equal to the additional coherent processing gain that would have been required in the absence of the proposed non-coherent processing scheme. This factor will depend on the size of the non-coherent burst of pulses, n, and on the nature of the interference environment. It will normally lie between $\sqrt{n}$ and n, and so can represent a very substantial cost saving.

Considerations Affecting Practical Applications

Assuming that simultaneous transmission and reception are not feasible, the minimum range of an echo-type target locating system is largely determined by the effective transmitter pulse length. Subsequent pulse compression would not reduce the time during which a high-power transmission paralyses the receiving

system. However, spreading the transmission over a burst of well-spaced pulses does help:—Reception is possible during the intervals between constituent pulses of the burst. Moreover, due to the unequal spacings between members, the " blind " ranges, when later transmission pulses obstruct reception of echoes from earlier members of the burst, are so staggered that, in any such range annulus, only one of the n echo pulses from the burst would be lost.

At short ranges (but exceeding one pulse interval within the burst) target echoes from early pulses may have to compete with clutter (*i.e.* reverberation) echoes from later members of the burst—and hence from substantially shorter range. If this effect is troublesome, the number of pulses in the burst may have to be restricted. Since the problem could only arise for short-range operation, such a reduction of burst length would normally be quite acceptable, indeed it might be desirable, in order to increase the inter-burst repetition rate whilst maintaining the mean and peak powers unaltered.

An incidental—and often advantageous—feature of the burst-transmission scheme is that demands on the primary power supply are more spread out, in time.

Limitations

The final processing stage shown in Fig. 2 is the combination of the echo-returns from a pattern of highlights, which jointly constitute a target. This process is inescapably non-coherent, and it will inevitably provide at least part of the processing gain required to raise wanted signals from the threshold of logical operations (here assumed to be +3dB) to the " recognition differential " giving the desired high detection probability and low false-alarm rate. This consideration sets an upper limit to the non-coherent processing that can be usefully applied to the constituent signal highlights.

The processing gain so exploitable may then have to be further shared between:

> Combining signals on the frequency-time " plane " (as with the proposed burst of pulses at progressively modified spacings): and
>
> Combining signals over the physical plane of the array aperture—where this is many square wave-lengths.

The " non-optimum " use of the available receiving aperture can give proportional economies, both in beam-forming networks and in the number of discrete beams producing inputs to the subsequent signal-processing system. Hence it will not always be desirable to employ all—or indeed any—of the " available " non-coherent processing gain in the manner proposed here. In the scheme suggested, the target echo from *each* of the constituent pulses has to compete with the returns, from any distributed clutter or reverberation, due to *all* the pulses in the burst. Similarly, in any non-optimum array processing, the performance against reverberation is degraded in proportion to the reduced initial angular resolution.) This feature must count against the use of such systems in applications where this type of reverberation is prevalent.

Conclusions

The basic philosophy of seeking substantially cheaper, not quite " optimum " solutions to signal-processing—or any other engineering problem—is of course far from original. The particular embodiment suggested appears to be particularly relevant to underwater acoustics, and may well warrant further consideration for quite a wide range of active sonar systems.

A MICRO-INJECTION TECHNIQUE FOR STUDYING BARNACLE HORMONES

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Introduction

Barnacles, as Crustaceans, belong to the group of animals known as Arthropods. In Arthropod species which have been studied, hormones have been shown to control the basic physiological activities and a common pattern has emerged in Insects and Crustaceans. Moulting hormones, or ecdysones, show a marked similarity in structure and mode of action: Crustacean hormones will effect Insects and vice-versa. Although little is known of hormone mechanisms controlling barnacles, it is to be expected that they are similar to those found in other Crustaceans and Insects. Such a view is supported by the demonstration (Barnes and Gonor, 1958a & b) of neurosecretory cells in barnacle nervous systems, by a possible mechanism for hormone control of breeding in a barnacle (Tighe-Ford, 1967) and by the work of Sandeen and Costlow (1961) and Costlow (1963) who found that extracts of barnacle nervous system have apparently the same pigment-activating effect when injected into crabs, as do crab chromatophorotrophic hormones themselves.

Although much of the knowledge of Arthropod hormone systems has been obtained by injection techniques, such an approach had hitherto not been carried out on barnacles because of the heavy calcareous shell surrounding the body. Such a technique for barnacles would facilitate research into the biological factors controlling development.

A method which permits barnacles to be injected with chemicals, hormones or tissue extracts over a period of time has been developed. Thus it is possible to follow the classical technique of injection and observation of the physiological response.

Structure of the Barnacle

The morphology of a typical acorn barnacle, the type normally found in fouling, is shown in Fig. 1.

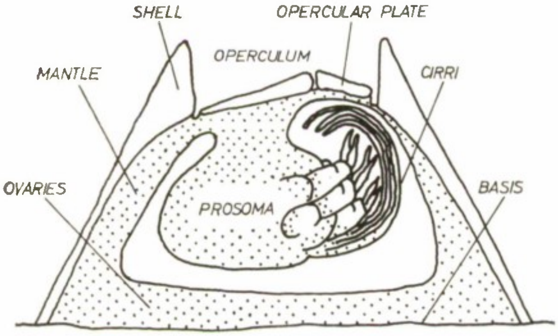

Fig. 1. Diagrammatic vertical section through a barnacle.

A barnacle consists basically, of a body or prosoma, lying within a shell which is lined with an extension of the body, called the mantle. This mantle tissue is responsible for the formation of the ovaries, the shell and the adhesive cement which attaches the whole animal to its substrate. The body is surrounded by a mantle cavity opening to the exterior through the operculum, which is closed by four opercular plates controlled by various muscles in the body and mantle. Feeding is carried out by six pairs of appendages (cirri) which sweep out through the operculum to catch plankton and detritus. The circulatory system consists of a blood space, or haemocoel, distributed through the tissue.

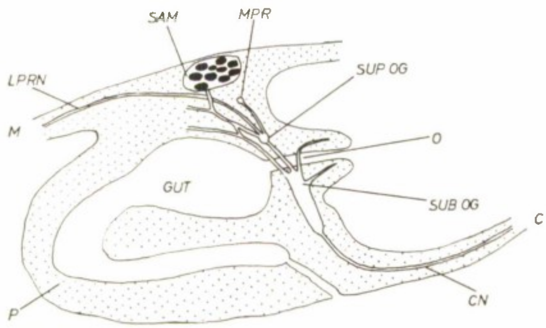

Fig. 2. The nervous system in relation to the prosoma of a barnacle. C—cirrus, CN—cirral nerve, LPRN—lateral photoreceptor nerve, M—mantle, MPR—median photoreceptor, O—oesophagus, P—Prosoma, SAM—scutum adductor muscle, SUB OG—sub-oesophageal ganglia, SUP OG—supra-oesophageal ganglia.

The nervous system comprises two groups of ganglia above and below the oesophagus, from which nerves branch to various parts of the body, shown in Figs. 2 and 3.

Neurosecretory cells, specialised for secretion, are concentrated in the sub- and supra-oesophageal ganglia. Such cells play a central role in the control of Arthropod hormone systems and those in the barnacle appear to have the same function. The types of neurosecretory cells found in the ganglia are shown in Fig. 4.

Three nerves arise from the supra-oesophageal ganglia leading to median and lateral photoreceptors ('eyes') which may be associated with the neurosecretory cells in the control of breeding in the barnacle *Balanus balanoides*.

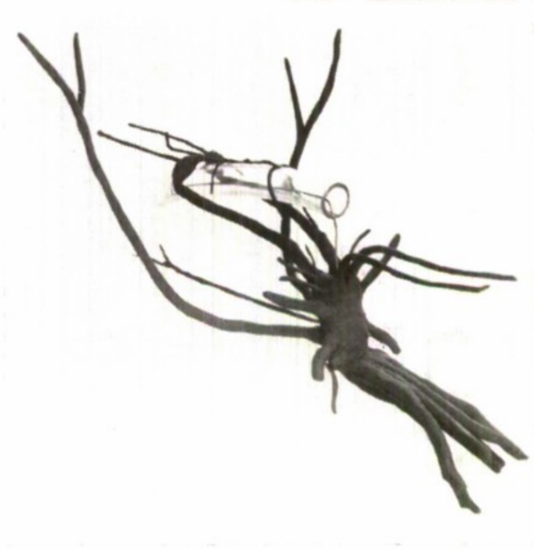

Fig. 3. Model of typical barnacle nervous system. The clear tubing represents the oesophagus.

Drilling and Injection Technique

Injections are made into the mantle tissue in the base of the barnacle to avoid damage to the opercular plates and to the body which contains the nervous system, gut, musculature, glands and male reproductive system. The only suitable areas for the injection site are the base or the sides of the shell. Injection through the base is unsatisfactory as this could only be carried out through a latex film or through the substrate upon which the barnacle had settled:

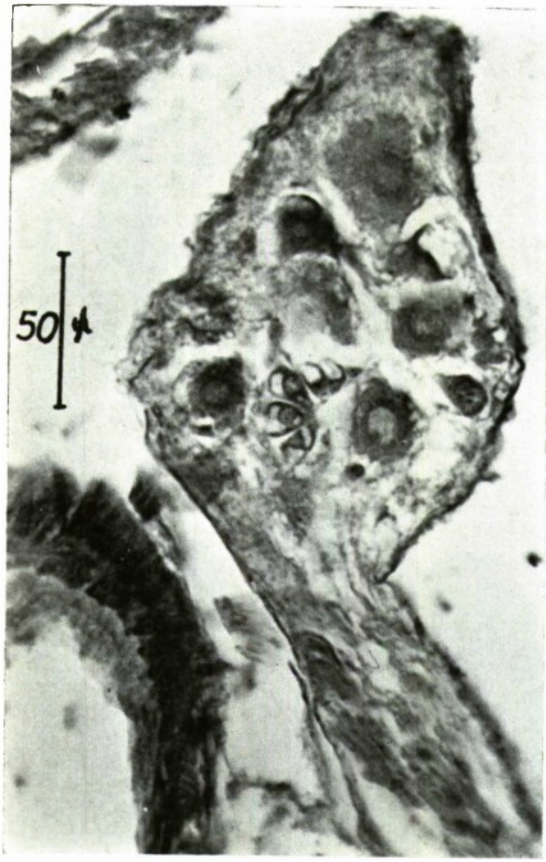

Fig. 4. Neurosecretory cells in one of the supra-oesophageal ganglia.

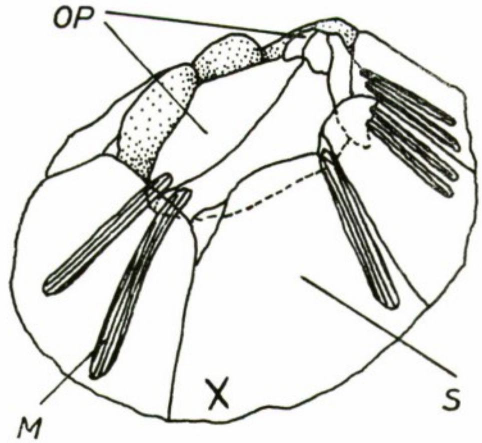

Fig. 5. The site of injection in the barnacle. M—muscles, OP—opercular plates, S—shell, X—area where hole is drilled.

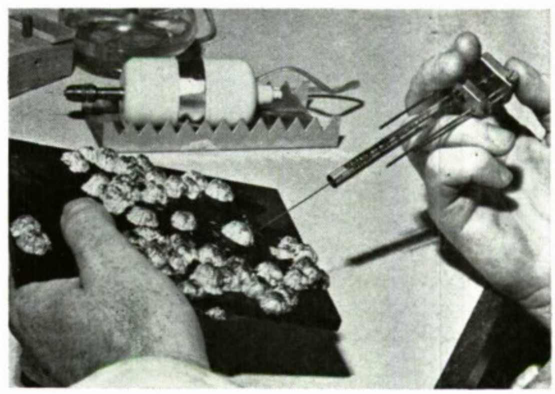

Fig. 6. Barnacle being injected after hole has been drilled.

with such a technique there would be considerable risk of passing through the mantle and injecting into the mantle cavity (see Fig. 1). Because of this a means was developed for drilling through the side of the shell and injecting into the mantle tissue.

The hole is drilled with a 0·65 mm hardened steel bit, fitted in a 12 volt, 1450 r.p.m. "Mini-drill". The site (see "X" in Fig. 5) is chosen to avoid the mantle muscles and the hole is drilled as near as possible to the base of the shell so that the needle penetrates longitudinally along the mantle.

The hormone or tissue extract is injected from a 100μl microsyringe which is inserted to a depth of 3 mm. The syringe is fitted with an automatic dispenser to give multiple 2μl doses. At the time of injection a few grains of the antibiotic "Crystamycin" (penicillin and streptomycin) are added to combat possible bacterial infection. The method of injection is illustrated in Fig. 6. After injection the hole is plugged with warm gutta percha (dental temporary filling) plasticised with cajeput oil. This forms a hard, waterproof plug which can be removed with a hot needle. Multiple injections can thus be made over a period of time.

Uses of the Technique

Approximately 250 barnacles have been injected employing the technique described above, using distilled water, nervous system and whole-tissue extracts and a purified crustacean moult hormone. The mortality caused by the technique itself is of the same order as that normally found in laboratory maintained populations and the activities of the barnacles are apparently unaffected. At present

this method is being used to investigate the effects of a known crustacean hormone on barnacle growth. In this experiment groups of barnacles have been injected five times at two day intervals with a range of hormone concentrations to study the qualitative and quantitative effects.

This experiment and other physiological studies are designed to see whether there is a correlation between barnacle hormone systems and those commonly acting in other Arthropods. Coupled with this work is a histological study of neurosecretory cells to determine sites concerned with hormone production and an investigation is also being made into the effect of barnacle extracts on known hormone systems in other Arthropods. As it appears that metamorphosis, growth, shell and cement formation may be controlled by one or more hormones, an understanding of these processes has obvious implications for antifouling research.

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QUEEN'S BIRTHDAY HONOURS

Her Majesty has been graciously pleased to make the following awards to members of the R.N.S.S. in her recent Birthday Honours List.

Mr. S. B. Kendrick, *Naval Construction Research Establishment*—O.B.E.

Mr. J. E. James, D.S.C., H.M.S. *Excellent*—I.S.O.

Mr. A. E. Caswell (Rtd.), *Admiralty Research Laboratory*—M.B.E.

Mr. W. G. Bown (Rtd.), *Admiralty Materials Laboratory*—M.B.E.

Sir William Cook, Chief Adviser (Projects and Research) and one time C.R.N.S.S. also received the award of K.C.B.

To each of these Officers we offer our sincere congratulations.

RAPID GENERATION OF BESSEL FUNCTIONS FOR SOLVING ENGINEERING PROBLEMS

Lt. A. J. Hissink, B.Eng.(Elect), R.C.N., and B. R. Gladman, B.Sc., A.R.C.S., R.N.S.S.

Admiralty Surface Weapons Establishment

Introduction Many problems in Electrical Engineering require Bessel functions for a given argument and all orders up to N, where N is often larger than the argument. This situation arises from problems with cylindrical symmetry where the evaluation of an infinite series involving Bessel functions is required. The function generators normally available in the computer library produce a value of the function for a given argument and order and in doing so calculate many other orders which are then discarded. This and an iterative process used to determine the starting point for backward recurrence cause very poor efficiency when meeting the needs of many engineering problems.

Bessel Functions[2]

Bessel's equation of order v is

$$x^2 \frac{d^2y}{dx^2} + x \frac{dy}{dx} + (x^2 - v^2)\, y = 0 \quad \ldots (1)$$

This may be solved by assuming a series solution of the form

$$y = x^v (a_0 + a_1 x + a_2 x^2 + \ldots) \quad \ldots (2)$$

The coefficients may be evaluated by substituting (2) in (1) and hence the definition of the Bessel function of the first kind of order v follows

$$J_v(x) = \sum_{m=0}^{\infty} \frac{(-1)^m x^{v+2m}}{2^{v+2m}\, m!\, \Gamma(v+m+1)} \quad \ldots (3)$$

where $\Gamma(z)$ is the Gamma function[3]

A second solution, independent for non-integer v, can be found by replacing v by $-v$ to give

$$J_{-v}(x) = \sum_{m=0}^{\infty} \frac{(-1)^m x^{-v+2m}}{2^{-v+2m}\, m!\, \Gamma(-v+m+1)} \quad \ldots (4)$$

Most writers, however, use the linear combination

$$Y_v(x) = \frac{\cos v\pi\, J_v(x) - J_{-v}(x)}{\sin v\pi} \quad \ldots (5)$$

instead. $Y_v(x)$ is known as the Bessel function of the second kind of order v.

It is often convenient to use another form, known as Hankel functions or Bessel functions of the third kind of order v. They are defined by

$$H_v^{(1)}(x) = J_v(x) + jY_v(x) \quad \ldots (6)$$

$$H_v^{(2)}(x) = J_v(x) - jY_v(x) \quad \ldots (7)$$

Finally, there exists an important recurrence formula[4] which allows the higher ordered Bessel functions to be expressed in terms of the

lower ordered ones or vice versa. It may be written as

$$B_{v+1}(x) = \frac{2v}{x} B_v(x) - B_{v-1}(x) \qquad \ldots (8)$$

where B denotes J, Y, $H^{(1)}$, $H^{(2)}$, or any linear combination of these functions, the coefficients of which are independent of x or v.

There are many more important properties and different forms of Bessel functions. This section is intended to serve as a partial reference for the section Method of Calculation.

Method of Calculation

The functions of very small arguments can be calculated efficiently using the first terms of the series solutions of Bessels equation[5]. For all arguments larger than 10^{-5}, the recurrence relations (8) between Bessel functions of adjacent orders provide a rapid and convenient means for their generation on digital computers. Starting with $J_0(x)$, $J_1(x)$, $Y_0(x)$, and $Y_1(x)$, these relations can be used to compute $Y_n(x)$ for any n and $J_n(x)$ for any $n \leqslant x$. Beyond this point $J_n(x)$ is a rapidly decreasing function of the order n and the recurrence process is unstable, there being a rapid loss in significant digits in the values produced. An alternative method of generation, valid in principle for any required order, produces $J_n(x)$ by backward recurrence. A value M is chosen which is rather larger than x or N, the highest order of interest. Starting values of zero and a small non-zero constant are chosen for $J_M(x)$ and $J_{M-1}(x)$ respectively and the functions of lesser order are generated from them by the recurrence relation. When the error introduced by the initial (incorrect) values is much larger than the rounding errors, it can be shown that the above process yields $F_n(x)$ rather than $J_n(x)$ where:

$$F_n(x) = \alpha J_n(x) \left\{ 1 - \frac{J_M(x)}{Y_M(x)} \cdot \frac{Y_n(x)}{J_n(x)} \right\} \qquad \ldots (9)$$

and α is a constant. The second term in the brackets is essentially a relative error and it is clear that $F_n(x)$ can be made proportional to $J_n(x)$ to any desired accuracy simply by ensuring that this term is sufficiently small. The value of α can be determined by summing a known series such as:—

$$J_0(x) + 2 \sum_{n=1}^{\infty} J_{2n}(x) = 1 \qquad \ldots (10)$$

during the recurrence process[6].

Two main difficulties arise with backward recurrence. Firstly, the error term discussed above does not become small until M is somewhat larger than the argument x and all orders up to this value have to be computed. Clearly if x is large and only a few low order functions are needed, this will be very inefficient. The second difficulty lies in the correct choice of the starting point M. This is fairly important since too low a value leads to inaccuracy while one which is too large results in more computation than is necessary. This latter problem has been effectively solved by the development of a simple analytic expression for the ratio of $Y_n(x)$ to $J_n(x)$ in the region where n is slightly greater than x and x is large. Although this formula has been developed using approximate relations[7] that are valid over a limited range (specifically $x \gg 1$, $n\text{-}x \ll x$), it has been found to give accurate results over a much wider range. The addition of a small empirically determined constant yields an expression that can be used for all arguments greater than 10^{-5}. The approximate value of n for which the ratio of $Y_n(x)$ to $J_n(x)$ reaches a certain large negative value is given by

$$n \simeq x + \left\{ \frac{3}{4\sqrt{2}} \, ln \left[\frac{-Y_n(x)}{2\, J_n(x)} \right] \right\}^{\frac{2}{3}} x^{\frac{1}{3}} \qquad x \gg 1, \quad n - x \ll x \qquad \ldots (11)$$

The empirical constant just mentioned has been found to be close to one half the coefficient of $x^{\frac{1}{3}}$ in (11), so that its addition gives

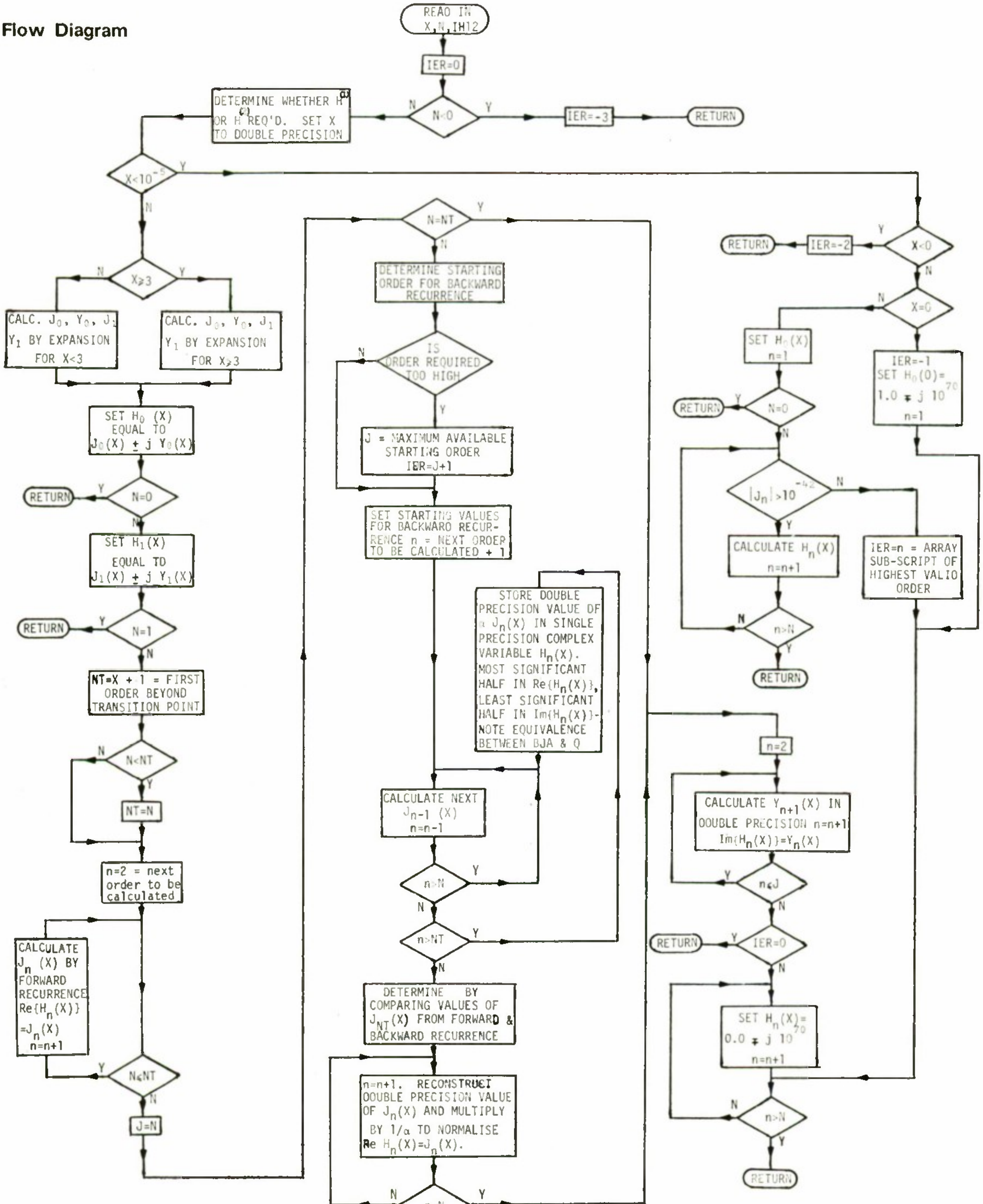
$$n \simeq x + \left\{ \frac{3}{16} \, ln \left[\frac{-Y_n(x)}{2\, J_n(x)} \right] \right\}^{\frac{2}{3}} (2x^{\frac{1}{3}} + 1) \qquad x > 10^{-5} \qquad \ldots (12)$$

From (1), if a relative error $\leqslant \varepsilon$ is desired at an order N, the recurrence must start at M, where

$$\left| \frac{Y_M(x)}{J_M(x)} \right| \geqslant \frac{1}{\varepsilon} \left| \frac{Y_n(x)}{J_n(x)} \right| \qquad \ldots (13)$$

Using (4) we can obtain an expression for M:

Flow Diagram



$$M \simeq x + k^{\frac{2}{3}} (2x^{\frac{1}{3}} + 1) \qquad \ldots (14)$$

where

$$k = \left(\frac{N - x}{2x^{\frac{1}{3}} + 1}\right)^{\frac{3}{2}} + \frac{3}{16} ln \left(\frac{1}{\varepsilon}\right) \quad N \geqslant x$$

In addition to efficiency, this formula offers a further advantage. The value of k obtained can be used to indicate the magnitude of functions generated by recurrence. For example, if $|Y_M(x)/J_M(x)|$, as determined from k, is around 10^{80}, then $|Y_M(x)|$ and $|J_M(x)|$ are of the order of 10^{40} and 10^{-40} respectively. If this exceeds the floating point range of the computer, an error message can be used to indicate that the users order and argument are not compatible. The convergence of many infinite summations involving Bessel functions is a direct consequence of their exponential behaviour when the order is larger than the argument. Equation (12) can be used to determine the point at which such series can be truncated without loss of accuracy.

The above arguments suggest that the most efficient method for Bessel function generation would be to use forward recurrence for $J_n(x)$ when $n < x$ and switch automatically to backward recurrence if higher orders are required. The constant α in (9) can be determined by comparing values calculated by forward and backward recurrence at the transition point ($n \simeq x$). $Y_n(x)$ would always use forward recurrence.

Sub-Routine Besh

A sub-routine making use of the above principles has been developed and found to be far more efficient for many electrical engineering problems than those in the computer library. It is more accurate, works over a wider range of argument and orders, and can be several hundred times faster than the unmodified library sub-routines. The function values are returned as a complex array of Hankel functions of the first or second kind depending upon an input variable. $J_n(x)$ or $Y_n(x)$ can be obtained by taking real or imaginery parts respectively. A listing of the program is available from the I.E.E. program library for a small fee, by quoting program C.P.57.

Sub-Routine Description

(a) Sub-routine title—Bessel Function Generator

(b) Sub-routine name—BESH

(c) Sub-routine details

- (i) Language—IBM Systems/360 Fortran IV
- (ii) Number of variables—13 Real*8, 4 Real*4, 6 Integer*4, and an array A where A is either
  an array of length (N + 1) Complex*8 variables. A(I + 1) contains $H_I(x)$
  or
  an array of length 2*(N + 1) Real*4 variables. A(2*I + 1) contains $J_I(x)$, A(2*I + 2) contains $\pm Y_I(x)$.
- (iii) Number of statements—119.

(d) *Performance Guide*

- (i) Computer used—IBM 360/65
- (ii) Core size required—3668 bytes (decimal)
- (iii) Input medium—Fortran coded cards
- (iv) Time taken per call—approximately [3 + 0·078 (highest order required)] msec.
- (v) Range of validity—positive arguments from 0 to 10^{14}, any non-negative order within core size limitations of output array.
- (vi) Estimated accuracy—to seven significant digits (with allowance for rounding errors), but when very close to zeros of the functions, accurate to 10^{-8}.
- (vii) Limitations—calling program must have a real array A when run under WATFOR. It may then be used as a complex array in calling program by means of the EQUIVALENCE statement. See Sub-Routine Description (c) (ii).

Acknowledgments

We would like to thank A. L. Cullen and J. B. Davies of University College, London and J. Croney of the Admiralty Surface Weapons Establishment for commenting on this article. We are also grateful to Mrs. P. Bourne for running this programme for us.

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(1) A shortened version of this paper has been accepted for publication in Electronic Letters by the I.E.E.

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(3) Abramowtz, M. and Stegun, I. A. (Eds.), "Handbook of Mathematical Functions", Dover, New York, 1965, 255 - 293.

(4) *Ibid*, 361.

(5) *Ibid*, 360, 369 - 370.

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(7) Morse, P. M. and Feshbach, H. "Methods of Theoretical Physics", McGraw-Hill, 1953, 631.

THE AUTHORS

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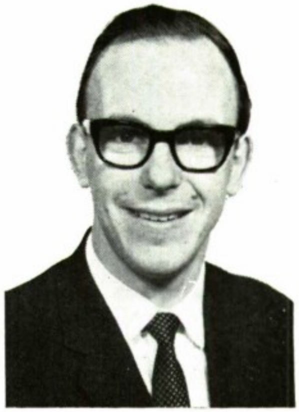
In 1967 the British Board of Trade awarded him an Athlone Fellowship for two years post graduate study in England. After completing a one year course in Microwave Engineering at University College, London and being promoted to rank of Lieutenant in 1968 he continued his studies for a Ph.D. degree. The subject, selected jointly by U.C.L. and A.S.W.E., was a study of the degrading effects of mast and guy wires on antenna performance in ships. The final year's work has been supported by the National Research Council of Canada in the form of a Post Graduate Scholarship.



Brian Gladman joined the R.N.S.S. in 1964, and worked until 1967 in the Antenna techniques division of the Admiralty Surface Weapons Establishment where he was involved in the development of electronically scanned antennas. From 1967 to 1969 he was the U.K. exchange scientist at the U.S. Naval Electronic Laboratory Center in San Diego, California. The major part of this period was devoted to the theoretical assessment of large, electronically scanned, cylindrical arrays. He has recently returned to Admiralty Surface Weapons Establishment and is now studying radio propagation at microwave frequencies.

DISPLAY DESIGN FOR NAVAL RESEARCH

Part I. Purpose and Presentation

A. R. Colberg

Technical Illustrators Pool (Naval)

The Manager Technical Illustrator Pools (M.T.I.P.(N)) has within his department "Design and Display Sections"; during recent years, it has been the practice of the Naval Scientific and Technical Information Centre to call upon the services of M.T.I.P. when participating in the organisation of Exhibitions, "Open Days" at various Naval Research and Development Establishments. This article is directed towards those concerned in the organisation of such exhibitions. It is hoped that it will also be of practical use to others when planning, preparing and producing exhibition material —Editor.

"Open Days" have been organised and presented by a number of Naval R. & D. Establishments, over the past few years, with varying degrees of success. Occasionally the exercise has been undertaken—in some cases unwillingly—by those who have had the task "wished" upon them and the result has in some respects confirmed this approach. We have all been faced at some time or another with the problem of mounting some sort of display at short notice, which has entailed much head scratching coupled with differences of opinion and eventually, the employment of paper, felt-tipped pens, drawing pins, coloured linen tape, bunting and other materials either begged, borrowed or manufactured. This has not been the case where better organisation and the benefit of someone who has a flair for visual display has operated but even then, unfortunately, the result has not always been 100% successful. A professional service is needed to answer the problems of presentation.

The important role that R. & D. has to play in this scientific and technological age, is being brought very much closer to the attention of Government, industry and the general public. In some areas, the future of establishments—coupled with economic standards—is being considered and this will necessitate the creation of an active image in the eyes of those vested with the power of enquiry and decision. These factors must be recognised in the approach to forthcoming "Open Days" where establishments subject to them will be "on show". Many officers of R. & D. establishments are familiar with commercially sponsored trade shows, exhibitions and travelling displays and, no doubt have been impressed by the presentation of technical information and equipment. When such invitations are reciprocated, as they are bound to be, commercial and industrial visitors will likewise be impressed by a similar standard of presentation, as well as those visitors from the Services and from the public sector.

This may sound logical but, the question will arise in responsible minds, how can this professional presentation be achieved within the R. & D. establishments? During the past three years, certain R. & D. establishments have realised and experienced the services of N.S.T.I.C. and M.T.I.P.(N), when successful "Open Days" have been presented in a professional way—*virtually within the resources of the establishments*. There are those who will argue that this approach is unnecessary and smacks of "fancy waistcoats". Is the abacus preferable to a digital computer? The argument should be; sophisticated research projects require a complementary presentation to reflect the high standard of research carried out, in some cases over a long period. Does such a project only merit a piece of cartridge paper bearing a drawing and legend executed with a felt-tipped pen, affixed with drawing pins to a piece of card propped up against complex equipment, together with coloured tapes cocooning the whole? The author accepts that, in certain cases, these methods have been necessitated by circumstances—very often at the last moment! Having outlined the need for good presentation, let us now examine the purpose of "Open Days".

The Purpose of " Open Days "

An establishment will obviously show the type of work with which it is concerned and the methods and equipment used. Within this basic purpose there are " factors of interest " to be considered. If the establishment has been operating for a number of years, the historical background, particularly its successes, may act as an introduction to the progress and development at the time of the " Open Days ". Special areas of research and development should be featured and, where applicable, related to industrial potential. Whatever the material and subject of display, the responsibility for carrying it out should not be passed to individual sections with the simple demand " put something on for the day ". This will inevitably result in varying standards which cannot present an overall image to the visitor. To prevent such a situation, particular attention should be paid to the planning and organisation of "Open Days" *at the very earliest opportunity.*

Planning and Organisation

When planning an " Open Day " it should be recognised that a disruptive effect upon the establishment may well be caused during the process of preparation. This is a fact, which some establishments in recent years have realised, when their respective " Open Days " were at an early stage of preparation. Obviously, steps must be taken early on in the planning stage to ensure that such disruption is minimal. But why should the establishment suffer disruption ? This depends largely upon the degree of participation in producing the various component parts that are required for a " professional " looking show. Component parts, in the context of this article, refer to the services of workshops, drawing offices, photographers, painters and others who produce the display material at the establishment. Past experience has shown that, where such services are employed during the " build-up " period, the day-to-day work must, to some extent suffer, when working to a specific " Open Day " target date. It is necessary to realise the priority rating for the work involved—which is not always easy—where important projects have to be considered and *also* require the meeting of target dates. The problem of priorities must be considered when the date of the proposed " Open Day " is under discussion. Better to be wise before the event than to proceed on a play-it-as-it-comes basis !

When the services of N.S.T.I.C. and M.T.I.P.(N) are called upon by an establishment, it is customary for them to make a preliminary " appraisal " visit to assess the facilities needed to produce the necessary display and publicity material. Their assessment, together with a draft plan of requirements produced by the establishment, can be of practical use when considering the date for an " Open Day ". This assessment will also be necessary for N.S.T.I.C. and M.T.I.P.(N) to prepare their own plans for production and to formulate a time schedule.

So far we have dealt with the purpose of the " Open Day " and the considerations of planning related to a proposed date. As our primary concern has been producing display material, it should also be noted that, other important requirements such as invitations, catering, transport, printed information (brochure and handouts) should be considered at the initial planning stage.

The Display Plan

The size of an establishment has an important bearing on the quantity and arrangement of displays. There are two basic approaches to the question of displacement of displays and the presentation of information; to concentrate displays within the laboratories and departments concerned or, to set up a central exhibition area which presents an overall picture of the establishment and its integral specialisations. In some cases a combination of the two can be employed. The central exhibition plan is more suited to a large establishment, where the visitor may be obliged to walk considerable distances and whose interest may fall in proportion to these extended locations. A visitor's time allocation is a very important factor, where he has to travel to and from the establishment by public transport. This usually requires the visitor to adopt his own time-table for arrival and departure from the " Open Day ", therefore, his time at the establishment must be spent profitably and not wasted by complicated routeing. The central exhibition plan should also provide facilities for cloakroom, general information desks and storage. If necessary, the inclusion of a cinema and press reception area can be considered. Supplementary displays, of a simple form, can be mounted at the places of interest, to provide the visitor with technical details. A central exhibition has the advantage of being impres-

sive at first glance and the facility for showing the visitor a comprehensive story of an establishment—in comfort. Having "sampled the wares", he can proceed at leisure to a particular department of interest and devote more time to examine the subject. In the case of a small establishment, a well planned route through departments will suffice, with comprehensive displays at appropriate vantage points. This is the general outline of the "display plan"; to examine the method of displaying information and exhibits we must consider the requirements in more detail.

Display Components and Information Media

"Open Day" information can be given in two forms; in the printed word and the three dimensional exhibit. The printed word appears firstly, in the brochure which the visitor should receive with his invitation, and secondly, in handout sheets which are available on the day. The brochure takes the form of a printed booklet, with photographs and illustrations, which summarise the function of an establishment and informs the visitor of the specialisations carried out in research and development. The handout is normally produced on special letterhead sheets and provides the visitor with technical details of a particular exhibit and its equipment or process, which he can retain and read after the visit. This latter point has an important bearing on the display panel—while interesting to the author—can be time consuming to the visitor and in some cases, defeat the object of the exercise. The object should be, to make a concise statement of relevant facts, easy to assimilate and comfortable to the eye of the observer. Extensive details can be given, at some length, in a handout sheet.

The display unit, which has now been adopted as a standard in the Naval R. & D. sphere normally takes a three dimensional form and comprises, a display panel mounted within a square metal tube frame construction containing a separate headboard and a table bench. (This unit can be re-used at other exhibitions and will, therefore, present a uniform display irrespective of the originating establishment).

The display panel provides an area for photographs, illustrations, printed text and specimens of equipment—(where size and weight are practical). Larger items of equipment and information sheets (handouts) can be displayed on the table bench. The "display unit" conforms to a standard height, with headboard and table bench of standard size. The length of the "unit" can be varied up to a maximum measurement of 8 ft. 0 in.

Supplementary display panels show the same component items as above (excepting the bench display) and may be fixed to a wall or similar structure.

A further article concerned with the working details of "Open Days" exhibits and requirements for printed material, is to be published in a forthcoming issue of this Journal.

THE DEVELOPMENT OF A TRAINING MODULE FROM AN OBJECTIVE TASK ANALYSIS

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H.M.S. *Vernon*

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For the past nine years he has been in the field of Anti Submarine Warfare training, having served at both the U.K. and Australian A.S.W. schools. Over the past four years he has developed and brought into service an audio visual training device as well as originating a new approach to objective training which has led to his present post as Training Methods and Course Design Officer in H.M.S. **Vernon**. He is due to leave the Royal Navy in October of this year and plans to emigrate to Australia.

Task Analysis

Research Educational Technologists have written a great deal on the subject of Task Analysis. They explain in great detail, and usually at great length, the principles and methods involved in making an objective task analysis, and the success, or otherwise, of their various ideas. An enormous gulf has resulted between these new ideas in Education and Training and the traditional methods employed by training officers who tend to perpetuate systems which have "grown up" in an almost acidental way. The "new thinkers" race ahead setting a scene which tends to have no players until the application of theory with practice is given a chance.

It was into a system of tradition that the new thinking Educational Technologists in the Royal Navy germinated their ideas which are revolutionising the approach to training. It is as an applicator and not as a researcher that I offer this article in the hope that others will be interested, and perhaps motivated to do likewise. These methods, which I found successful, will inevitably be improved, but perhaps they may serve as guide lines for those in the field who are in a position of "having" to find a way where all else has failed.

The system I shall describe, by its very logical nature, must have proven successful, but that the students liked and understood it, produced a much greater success than could ever have been hoped for in the early stages of its introduction.

The basis of the " method " is a synthesis of an analysed skill into the following seven levels:—

1. Jargon: Definitions: Language.
2. Recognition and location of:—
   a. major components; b. sub-components; c. operator switches and controls etc.
3. Statement and recognition of effect of switches and controls.
4. Carrying out switching and control (out of context).
5. The Statement of Drill, procedure or action.
6. The Carrying out of Drill, procedure or action.
7. The Recognition of a situation when Drill, Procedure or action must be carried out.

I believe the seven levels to be applicable to any definable skill and by their very application enable the synthesis of a task analysis to take place and thus produce a training sequence from an otherwise non-sequential Scalar diagram.

Each level stated is quite objective and should not produce any overlap with the next stage. But before progressing let me describe the levels intended in more detail.

Jargon, Definition and Language

Level 1 The description of each level in this paper is in fact, " Level 1 ", and if the objectives of this paper are to be achieved, it will be necessary for any new Jargon or Definition not already understood by the reader to be introduced.

Some would include the word " motivation " which is a great " yard arm clearer " for the introduction of a topic by the inclusion of something just " felt " necessary—to introduce any topic by means of something not actually required must be, in the purest sense, absolutely unnecessary, but under the heading of motivation would be a task promoting endless argument, and I will not begin it.

This level is intended precisely for those words, and descriptions not previously met or contained in the vocabulary of the student which are essential for the translation into understandable action of the rest of the sequence.

Recognition and Location

Level 2 As it must be assumed that the equipment or task is " brand new " in the analysis, each and every major component which houses or contains each and every sub-component which in turn may contain, house or site an operators control must be recognised and located by the student.

To locate means responding to a command such as " Where is the lever x ? " or " the switch y ? " etc. and never a response to the question " What is the name of this lever ? " having indicated " lever x " or " switch y ".

Only those components, in such detail, as is required in the later sequences will be necessary.

Statement of Effects of Switches or Controls

Level 3 Before controls are manipulated a student must " know " what the effect of that control will be. In some cases the " knowledge " will be a recognition of it being completed or applied correctly (as in the case of a switch) in others a complete recognition of all the possible effects of a particular control (such as radar strobe).

Carrying Out Switching or Controls

Level 4 This stage will often be carried out at the same time as Stage 3 but in any case will depend absolutely on it, the effect of manipulation must be recognised before a student is allowed to actually do it, in some instances such pedagogy seems unnecessary but in all cases the two stages must be progressed with or without realising that they have been passed; otherwise the " objective " of a particular control would not be recognised when it has been operated—particularly if that control malfunctioned.

Statement of Drills and Procedures

Level 5 This is really again a dual stage with:

Carrying out Drills and Procedures

Level 6 This, together with 5, will be absolutely necessary if any specialised sequence of operation is required over and above an absolutely arbitrary control or manipulation of those items dealt with in Levels 3 and 4. In the Ser-

vice content Drills will come under this heading, and are particularly difficult to train as they are not necessarily logically consequent upon each other.

Recognition of Situation when to carry out the previous Levels

Level 7 This final stage will be required as long as an operator or student is required to discriminate when he must do something. Sometimes it will be implicit in a particular operation (*e.g.* " if the light comes on, do this " . . .). However, it is really intended as the supervisory stage when operations which require external initiation, and therefore, require a controller. This stage will have many applications in real situations.

These seven levels can be illustrated specifically in a complete " module " of training which has been developed to achieve the following training objective:

> " That on completion of the module, the trainee will be able to operate Sonar Type 177M, carrying out the drills and procedures listed in the specifications without error at each console of a simulator in real time.

The formulation of such a module is clearly the key to the whole problem of enabling a student to " do " almost anything, as long as it can be clearly defined.

This particular stage-by-stage approach is but one type of ladder to reach the summit. There may well be others but any logical ladder, once formulated, will provide a basis for the future improvement of a student's training and proof of his achievement, should this not itself be quite obvious, when he has completed the module.

The task analysis, such as proposed by Mager[1] is an invaluable aid in the formulation of a module. But it is the module itself which is the link to the " course design " so frequently referred to in a conventional training system and so often the result of stringing together intuitive thoughts upon what has always been thought as necessary in a traditional course. In order to appreciate this in more detail I must develop an argument in somewhat semantic terms.

If a job is defined as "All the tasks carried out by a particular worker . . . " (DEP Glossary of Training Terms[2]) then surely a task analysis, is, as the same reference quotes, a " systematic analysis of the behaviour required . . . " for each of the tasks of a job, and necessarily provides a detailed map of the whole area in question (usually in the form of a Scalar diagram).

In order to transit this area, a route is required which must be continuous and acceptable to the trainee.

The pure task analysis " map " will provide a picture of the whole area and should leave no spaces, but it will not necessarily provide a logical sequence of covering a particular route.

It is for synthesising such a route that I proposed these seven levels for use with any Scalar diagram detailing a complete job analysis (with its associated test specifications and detailed sheets of information). Specific Tasks, or groups of tasks which are themselves the end product of a seven level approach must be extracted from the Scalar; a Module can then be synthesised from it by slotting into each level the necessary components extracted from the legs of the Scalar diagram beneath the first Tasks extracted.

A typical Scalar diagram is illustrated from which the above module was developed. This Scalar has been left at the definitive task stage for brevity. But the components which would have appeared are those which now form the completed Module.

Frequently, the transfer of components from the Scalar will be from several legs in parallel meeting the same task above. This will be so, particularly if the drill is involved. To " carry out drills " may involve a set of drills all on the same instrument and the early stages of the seven levels will have been the same for each drill and will not require repetition. It is at this point that one must realise that " a Drill " is a task analysis in its own right and only if it is required to formulate new drills can one apply task analysis of the form and detail suggested by Mager[1].

Thus, by applying the seven levels to a set of drills only the question of order of drills will be posed, and this is usually intrinsic in the nature of them.

This process of extracting the sub task elements from the Scalar diagram must be completed for all those elements below the definitive task selected and only when it has been completed will any " complete " module emerge.

As a complete course may involve several definitive tasks, some of the " lower legs " of the Scalar may well be repeated. This will

become apparent by inspection and must be checked against other modules of the course to avoid duplication. The very synthesis of the seven levels will aid this check as the " leg " in question would appear in the same level of another module.

SONAR TRAINING MODULE

Level	Object	Method
1	(Definitions, interest, motivations)	A Film
2	Location of consoles: Knobs and Switches Required in Drills	B A.V.I.T.
3 & 4	Location on Real Set. Effect and actual setting of standard settings.	C C.C.T.V./ simulator
5	Sweeping procedures Learn to state.	D A.V.I.T.
6	Carry out sweeping procedures when ordered.	E C.C.T.V./ simulator
5a	Initial and lost contact procedures to state.	G A.V.I.T.
6a	To carry out contact procedures.	H Simulator
7	Recognition of echoes. Test on recognition of echoes.	F A.V.I.T./ simulator

FIG. 1. Unit for one Sonar Set

It is only likely that such duplication will appear at the lower levels of the synthesis as the end products of each module are discreet by definition.

I will now develop this article to deal with some points which arise in the actual conduct of the module in a training situation. In the process of formulation of a task analysis within an objective training system, objectives and their associated test specifications will emerge, and it is to these specifications that the sights must first be turned. Once a module of training has been formed it can be entered at many levels by the trainee—that is, if the ability to carry out the objective of the lower levels is already held.

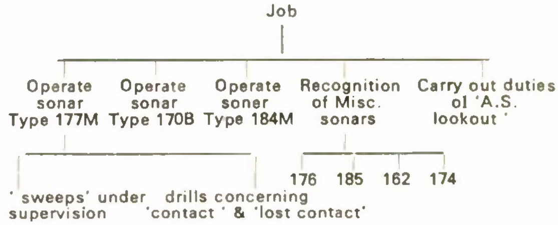

FIG. 2. Scalar diagram on U.C. basic ' Job at Sea '.

To determine whether or not a student has a particular skill, a " Pre-Test " should be developed and given to everyone before they begin a module. Ideally a pre-test should exist for each level, but in practice it is usually found that a few well thought out questions will determine the " pre-knowledge " of the entrant and enable the instructor to allow him to miss out a lower level, or not.

The individual approach will become very difficult in the conventional class situation, but in a free running system (as mentioned below) it is very simple to operate.

Testing of the achievement of each level is absolutely necessary, for until a student can " do " each stage he must not be allowed to progress, and the correct test, properly applied, will be the media through which he must pass to progress from level to level. Again this becomes idealogical unless applied in the free running sense, as some compromise has to be exerted when a whole class has to be programmed from stage-to-stage.

However, if the length of time allowed is carefully chosen the bright students, and those quick to learn, will not become too bored whilst waiting for their more unfortunate brethren to catch up—they may even be used to assist them.

This doctrine of ability must be applied at each level—however—all systems will be malleable and at the " Statement of procedures " stage it would be very wasteful of time to insist on a ' By Heart ' standard before allowing the procedure to be tried. The very practice of this procedure will assist the learning of its sequence and so must be accelerated in the process. A " link " in the form of a " cue card " check-off list or other such *aide mémoire*, will be substituted for the comnlete learning by heart, and the level concerned can simply have added to its stated objective, "with the aid of a cue card." Such a card is illustrated in Fig. 3. The objective of the level then becomes, particularly in the case of complex drills and procedures, a

ORDER BY SONAR CONTROLLER	RANGE RECORDER	SECTOR DISPLAY	DOPPLER DISPLAY
"Hunter – STANDARD SWEEP AXIS .... deg"	SWITCH TO NORMAL	REPEAT ORDER TRAIN Td TO AXIS Hold SWEEP AUTO PAGE CHANGE	
"Hunter – MANUAL ECHO SWEEP from ..... deg to ..... deg"		REPEAT ORDER TRAIN } STEP } AS ORDERED Hold SWEEP PAGE CHANGE STEP AS ORDERED	
"Hunter – AUTO H.E. SWEEP	OFF/TEST TX.	REPEAT ORDER Hold/SWEEP	BRILLIANCE DOWN SELECT POS'N 3 ADJUST BRILLIANCE
"Hunter – MANUAL H.E. SWEEP from ..... deg to ..... deg"	OFF/TEST TX.	REPEAT ORDER HOLD Sweep TRAIN	BRILLIANCE DOWN SELECT POS'N 3 ADJUST BRILLIANCE
"Hunter – INVESTIGATE ..... deg"		REPEAT ORDER HOLD Sweep OFF TRAIN PAGE CHANGE	
"Hunter – NEW AXIS ..... deg"		REPEAT ORDER OFF TRAIN AUTO CHANGE	
THIS SYMBOL MEANS	CHECK STANDARD SETTINGS AND AMEND AS ORDERED BY SONAR CONTROLLER		

FIG. 3. 177M Cue Card.

translation into everyday words the inevitable jargon and sequence of the cue card.

The carefully produced cue card will become a return point for future retraining processes, when a skill has become rusty by lack of practice or even just forgotten.

In producing "cue cards", only cue words are necessary to call to mind the action or response necessary. It is interesting to note that the drills themselves undergo a very thorough "logical" analysis when such cards are produced. In many cases a drill just happened which was "accidental" or was "understood". Such drills require amendment in full before cue cards can be formulated.

The cue card illustrated in Fig. 3 resulted from lengthy discussion and reappraisal of eight pages of complex description in the existing drill book and is typical of the results of this process being applied to traditional methods. In all such discussion and analysis the applicator will have the greatest difficulty in isolating the true objective of a drill or procedure, from particular things which have "always been done" or which are just as necessary.

The "class" concept of training is at best a compromise, for the ideal, a personal tutor must be superior. Progress will always depend on the ability of the individual. The human instructor can adjust his presentation according to the mood of a class, but can only allow for the effect of a very slow individual on the others and at best retard everyone to the pace of the slowest.

A completely automated development such as the Dia. Pilot discussed in the *Journal of the Royal Naval Scientific Service*, **24**, 6 (November 1969) cued incorrectly without a supervising instructor will be less capable than an unaided instructor. The automated presentation, without being guided, cannot even adjust to a different class mood. However, an individual automatic device, properly programmed has every advantage in that it is equivalent to a personal tutor, yet inhuman and faceless, consequently even the most concerned of students will not mind asking questions of it or "lose face" by doing so (such a device as AVIT is ideal for this purpose).

Once a complete module has been programmed, and automatic material available for it, then a completely new concept of training is possible. This will be called "Free Running" and the training module becomes an assembly line for training individuals. The concept is easily understood whereby trainees move through the module at their own pace constrained only by the availability of equipment or the particular needs of the procedure for which they are being trained. (In the case of the sonar operators module they "free run" in groups of three men. This was necessary because of the sonar set requiring a team of three operators and with limited equipment, moving three men at a time proved to be the most efficient use of equipment within its other programmed requirements.) Source illogicalities and equipment constraints will make other artificial aids necessary in this form of training, each being developed when a difference exists. An example of this, in the module illustrated, was the simulator limitation. Ideally one simulator should be available for each group of three trainees with AVIT machines actually alongside, whereby the Module could be completely freely integrated. Trainees would progress from machine to simulator and back. Unfortunately, and almost obviously, no such equipment exists and the AVIT machines are housed in a separate building from the simulators. Another link became necessary and CCTV provided the answer. It was possible to instal a CCTV monitor alongside the actual simulator and go

through the objectives one by one immediately following an AVIT lesson. These objectives are only repeated and illustrated and provide a form of pairing which provides a link in an otherwise discontinuous process with machine and simulators so far apart.,

Once a module has been formulated and completed for each level of training the resulting material will have a use for objectives other than the terminal objective of the module itself. A very good example of this use will be for the training of management when an "understanding" is demanded but not necessarily the operative skill. Quickly and easily, the training can be adapted and the loose semantic description of understanding defined absolutely, so that the manager will do levels 1, 2, 3 and 5 in order that his true function of level 7 may be attempted.

Other quite differing uses of the module will become apparent and develop from quite legitimate requirements for various forms of instruction about the machine or material in question. (A further example of this has already been found in the module illustrated by a film maker and an equipment designer.)

Finally one must postulate clearly that when a module exists for all the various components of a particular training course then this course design problem will have been solved, The Course Design has become an exercise in logically achieving an objective, an exercise which surely must be the aim of all trainers and trainees.

References

(1) Mager, R. F. Developing Vocational Objectives, Fearon 1967.

(2) Glossary of Training Terms, D.E.P. H.M.S.O. 1967.

ADMIRALTY ENGINEERING LABORATORY GOLDEN JUBILEE

The Golden Jubilee Open Days celebrating 50 years of Research and Development at the *Admiralty Engineering Laboratory* were held 14 - 17 July 1970. Many distinguished visitors from home and abroad attended the V.I.P. day, Tuesday 14 July, including Vice Admiral Raper, Director General Ships, Mr. Fitzer, Director Engineering (Ships) and the Mayor of Hillingdon, Councillor C. Rogers. About 60 members of the Press attended on Wednesday 15 July resulting in many reports appearing in the national and technical Press. About 3,000 guests were received during the week in addition to the many visitors who attended during Families Day, Saturday 18 July. The Controller of the Navy, Admiral Sir Michael Pollock (now First Sea Lord) and Mr. B. W. Lythall, Chief Scientist (Royal Navy) were welcomed to A.E.L. on Monday 21 July and their tour of inspection was extended to include other research and development projects which, for reasons of security, were not on display during the previous week.

Mr. Woodley, S.E.E., Deputy Head of the Electrical Department was responsible for the detailed planning and organisation of the Open Days. The many letters of congratulations received by the Superintendent, Captain Humphrey, bear witness to the success of this venture and to the untiring efforts of all the A.E.L. staff to make it so.

A more detailed account of the A.E.L. Open Days will appear in the January issue.

Mechanics of the Knee Joint in Relation to Normal Walking

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Abstract

Experimental measurements of normal walking were taken using male and female subjects. The mechanics of the knee joint were simplified and defined in mathematical terms. By considering the normal knee joint to function according to the mechanical principals thus defined, the forces transmitted by the joint were calculated from the experimental data.

The general mechanical concepts of knee action are outlined and the assumptions made in defining the joint 'model' described. The results obtained are presented and discussed in relation to the assumptions made.

Introduction

Although many studies have been carried out in the field of joint action, investigations have in the past been mostly confined to the analysis of movement. Experiments aimed at the analysis of forces acting on the joints and in the surrounding connective tissues are few and of a limited nature. The information available on the function of the knee joint is generally derived from two sources, namely the study of normal gait, and experiments conducted on cadavers.

Information obtained from the study of normal gait is limited by the difficulty of measuring accurately internal movement of the joint due to the presence of the surrounding tissue. For example, while rotations about the long axes of the femur and tibia have been recorded in gait studies, (Inman *et al.*, 1948), the position of the long axis of rotation of the joint (taken to be parallel to the long axis of the tibia) relative to the knee joint is still obscure.

Observations made by study of knee joint action in cadavers are limited in their relation to normal joint function in that the joint is not subject to the force systems arising in normal joint action. While these experiments allow the investigator to record at which joint positions the individual ligaments become taut and to which movements of the joint they exert a restraining force, quantitative assessment of the restraining forces applied to the joint by the individual ligaments cannot be made nor can the relative importance of their role in walking be deduced. Literature describing the function of the ligaments at the knee, although abundant in nature, is often in disagreement. Brantigan and Voshell (1941), review contradictory statements made by different authors and present the results of experiments on cadavers which assess the validity of these statements. Despite this, contradictory statements regarding the function of the ligaments continue to be made.

The function of the musculature has been studied in greater detail. Much useful information regarding the function of the muscles and the phasic relationship of their activity has been obtained by the development and use of electromyography (University of California, 1953; Lippold and Bigland, 1954; Basmajian, 1962; Close, 1964). Experiments involving the electrical stimulation of muscles have greatly clarified the relationship of muscle force to muscle length and velocity of shortening (Roberts, 1967). There is yet, however, little information as to the magnitude and interrelation of these quantities during normal physical activity such as walking.

Forces acting across the articulating surfaces of joints have recently received much attention due to their importance in the design of internal prostheses and in the understanding of joint lubrication problems. The external force system acting at the knee joint has been measured by several researchers, Elftman (1940), Marks and Hirschberg (1958), Bresler and Frankel (1950). Total force acting across the joint, however, has not been investigated in detail prior to the present study. In a previous publication by the author (1968), total force transmitted by the knee joint during level walking was stated to have a maximum value of 2 - 4 times body weight. Forces acting at the hip jont in level walking have been measured in normal subjects by Paul (1965) and in subjects having prosthetic replacement of the femoral head by Rydell (1966). Rydell measured maximum force at the hip of a male and female subject to be of the order of 1·8 and 3·3 times body weight respectively. Paul calculated maximum joint force to be in the range 2·3 - 5·8 times body weight.

Experiments designed to estimate the coefficient of friction in human joints have been reported by Charnley (1959), McCutchen (1962), Barnett and Cobbold (1962), and Rydell (1966). These experiments indicate the friction coefficient to be in the range 0·002 - 0·04. A coefficient in this range is superior to that achieved in engineering bearings of similar structure.

At this point it is appropriate to mention the controls imposed on joint movement by the muscles and ligaments and the natural range of these movements during normal walking. In the following section, therefore, a description of the fundamental concepts of the mechanics of knee action, upon which knowledge the present work is based, is given.

General Mechanical Concepts of Knee Action

The knee is extended by the quadriceps femoris, asisted by the tensor fasciae latae. Flexion is caused by the hamstrings, assisted by gracilis and sartorius. Gastrocnemius and plantaris are also flexors of the knee. Movements of the joint in other directions are prevented mainly by the binding effect of the ligaments and the geometry of the articular surfaces.

Backward gliding of the tibia relative to the femur is controlled by the posterior cruciate ligament, and forward gliding of the tibia is controlled by the anterior cruciate ligament. Most authors state that adduction of the joint is prevented by the lateral collateral ligament and the cruciate ligaments, abduction by the medial collateral ligament and the cruciate ligaments (Brantigan and Voshell, 1941; Gray's Anatomy, 1962). Steindler (1955), however, maintains that this movement is checked entirely by the collateral ligaments. The medial collateral ligament and the cruciates, acting together, limit rotations of the femur on the tibia (*i.e.* about the long axis of the joint) in all positions of the joint. The lateral collateral ligament resists lateral rotation when the joint is in extension. Medial or lateral movement of the femur on the tibia is prevented by interaction between the tibial intercondylar eminence and the femoral condyles, and the restraint of

the ligaments. Joint movement is mainly a relative sliding motion of the opposing condyles. In the last 10 - 20° of extension, however, the femoral condyles roll forward slightly on the tibia. As the radius of curvature of the femoral condyles decreases from front to back, the medio-lateral axis of the joint varies in position, depending on the angle of flexion.

In normal walking, rotations about the long axis of the joint are small, having a mean range of about 9° (Inman *et al.*, 1948). Rotation occurs in the last few degrees of extension but the exact mechanism is uncertain (Gray's Anatomy, 1962). Steindler (1955) and Morris (1953) state that the axis of rotation lies closer to the medial condyles while Gray (1962) states that it passes through the lateral condyles. The knee resists adduction and abduction in extension, a limited movement being possible in flexion (Gray's Anatomy, 1962). Greatest flexion of the joint during walking occurs in the swing phase and is of the order of 75° (Berry, 1952). For most of the stance phase flexion is less than 20° but increases to about 55° at toe off (Berry, 1952).

Functional concepts for analysis

In order to calculate the forces transmitted by the joint articulations and the connective tissues under dynamic conditions it was necessary to define the joint structure and the mechanics of its action in mathematical terms. Further, the mathematical model as constructed had to be such that an unique solution of force actions could be calculated for any position and loading of the joint. In order to satisfy this condition and in view of the several aspects of joint mechanics not clearly defined in the literature, the joint structure and function as defined in mathematical terms involved a degree of mechanical simplification. The functional concepts adopted are described as follows.

A set of reference axes X_s, Y_s and Z_s was adopted in relation to the tibia. These axes are shown in Fig. 1. The directions of all forces acting across the knee joint were defined in terms of this system of tibial axes (see Fig. 2).

The near cylindrical configuration of the femoral condyles and the relative flatness of the opposing tibial articulations implies approximately a line contact of surfaces in the medio-lateral direction. In the analysis a line contact was assumed and its position on the articular surfaces taken to be coincident with the Z_s axis of the tibia; (Fig. 3). Anterior-posterior displacements of the line of contact from the Z_s axis due to the rolling of the femoral condyles on the tibial condyles in

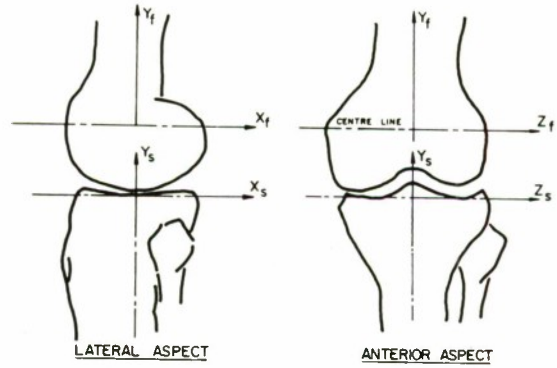

FIG. 1. Reference Axes of Femur and Tibia.

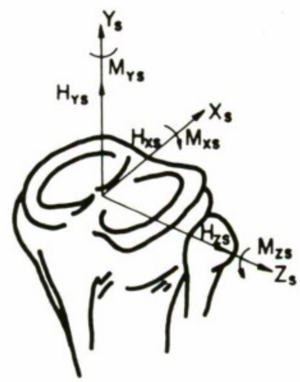

FIG. 2. External force system acting at knee—Expressed in terms of Tibial Reference Axes.

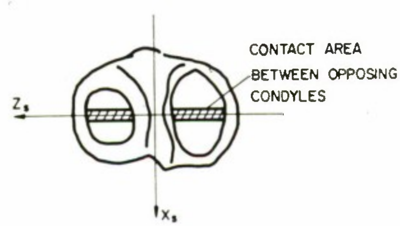

FIG. 3. Tibial Condyles—Superior Aspect—showing assumed contact area of Tibial and Femoral Condyles.

extension were neglected. It was further assumed that the femoral condyles rotated relative to the tibia about a fixed centre line parallel to the Z_g axis and intersecting the Y_g axis of the tibia; (Fig. 1). This centre line was taken to be coincident with the axis of rotation of the knee joint in the position of 180° extension.

Muscles and ligaments of the joint were defined by the position of their attachments and for this purpose a further two sets of axes were adopted. Axes relative to the pelvis X_p, Y_p and Z_p were assumed to have origin at the anterior superior spine of the left hip bone, and to be coincident with the intersections of the planes of the body drawn through that point. The femur was defined by axes X_f, Y_f and Z_f, having origin at the intersection of the assumed centre line of the femoral condyles and the Y_g axis of the tibia (see Fig. 1). The Y_f axis represents the mechanical axis of the femur and the Z_f axis is coincident with the centre line of the condyles. The error in the assumption of a fixed point origin on the femur relative to the axes of the tibia is small, but increases with degree of flexion of the joint. The true position of the origin on the femur subject to 90° of flexion is shown in Fig. 4. A detailed discussion of this movement is given by Steindler (1955).

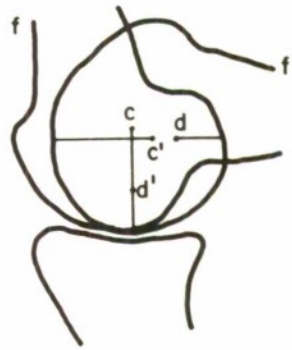

FIG. 4. Centre of Rotation of Femur
C, C'—Centre of Rotation at 180° extension
d, d'—Centre of Rotation at 90° flexion
Error in assumed fixed point origin at 90° flexion—distance CC'.

Extension or flexion of the knee was controlled by forces acting in the quadriceps femoris, hamstrings or gastrocnemius muscle groups. As the hamstrings and gastrocnemius muscles both tend to flex the joint, electromyographic data describing muscle activity during the walking cycle was used to decide which of these two muscle groups were active at a given instant. Details of the choice of these muscle groups and of the method of determining their force vectors relative to the tibial axes are given in a previous publication (Morrison, 1968).

The force transmitted by the joint articulations was considered as two components, a direct compressive force R_y acting in the direction of the Y_g axis of the joint, and a side or shear force R_z acting in the medio-lateral direction. Force R_z was assumed to be transmitted partly as a friction force acting between the faces of the opposing condyles, and partly as a compressive force acting between the concave inner boundary of the tibial condyles and the inner boundary of the femoral condyles. The effects of friction in the joint in the anterior-posterior direction was neglected. It was therefore assumed that an anteriorly directed force on the tibia was resisted by the anterior cruciate ligament whilst a posteriorly directed force was resisted by the posterior cruciate ligament. The direction of the force imposed on the joint by a ligament was defined in terms of the positions of the ligament's attachments relative to the tibial axes.

Moments of adduction or abduction acting on the joint were equilibriated by a redistribution of pressure on the condyles, *i.e.* a displacement of the centre of pressure along the line of contact of the condyles from the joint centre. As pressure on one condyle tended to zero, further loading in this direction was resisted by a reaction in the collateral ligament of that condyle. Torsional action at the joint (*i.e.* about the Y_g axis) was neglected. The effect of torsion on the calculations is discussed in the presentation of results.

Experimental procedure and analysis

In the following paragraph a brief account of experimental procedure and analysis is given. Details of this section of the investigations are presented in a previous publication (Morrison, 1968).

Subjects were filmed from the front and side whilst walking along an instrumented walkway (see Fig. 5). Reaction between ground and foot during one step was measured by a force plate. Accelerations of limb segments were calculated from measurement taken from

the cine film records. The external force system acting at the knee joint was then calculated by summing ground force and acceleration forces acting on the limb.

By considering the knee joint to operate according to the mechanical principles described in the previous section and applying the experimental results to this 'joint model', a complete force analysis of the joint under dynamic conditions could be achieved for any position of the walking cycle. By computing forces in this manner for each consecutive frame of cine film recorded, the force cycles acting at the articular surfaces and in the muscles and ligaments were obtained.

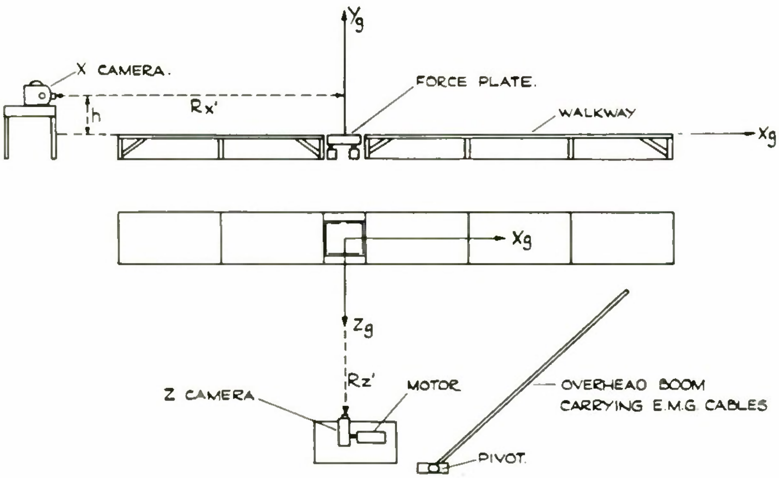

FIG. 5. Diagram of walkway viewed along the Zg axis (above) and Yg axis (below).

Results

The results presented describe fourteen experiments involving three female and nine male subjects. All subjects were normal adults, 11 being in the age range 18 - 24 years and one male of age 38 years. It should be noted that where average figures are presented, to prevent bias of results towards subjects tested more than once, the average values obtained from tests on these subjects are considered in conjunction with the values obtained in single tests on the other subjects. In the following discussion the phrase 'joint force' denotes the compressive force R_y acting normal to the articular surfaces of the tibia. Considering component R_z to be totally transmitted by the joint surfaces, the resultant values of the two force components R_z and R_y are of the order of 0 - 2 per cent greater than the values of 'joint force' (*i.e.* component R_y) quoted in the results. In all cases the joint force is measured as a fraction or multiple of the body weight of the subject.

The complete solution of forces is presented for three subjects in Figs. 6 - 10. The results shown in these figures are considered to be representative of the range of results obtained. In each figure the results obtained for the three subjects are superimposed in order to indicate the degree of variation in force systems developed by different subjects performing the same activity.

(1) *Muscle forces*

Maximum force values in the region of 400 lb. were calculated in all three muscle groups. Mean maximum forces developed by the twelve subjects in the quadriceps femoris, hamstrings and gastrocnemous were 167, 270 and 234 lb. respectively.

Force actions calculated in the three muscle groups (Fig. 7) may be explained as follows. Immediately prior to heel strike, force action in the hamstrings decelerates the forwards motion of the leg. At heel strike the foot is positioned well in front of the knee and hip joints and hence vertical force acting on the foot causes a moment, $-M_z$, to act at both joints. In most experiments this moment was increased by the action of an anteriorly directed force on the foot at heel strike. This moment action is resisted by force action in the hamstrings which, having a biarticular function, stabilizes both the knee joint and the hip joint (assisted by the gluteal muscles). The advantage of the biarticular muscle in these circumstances is illustrated by Elftman

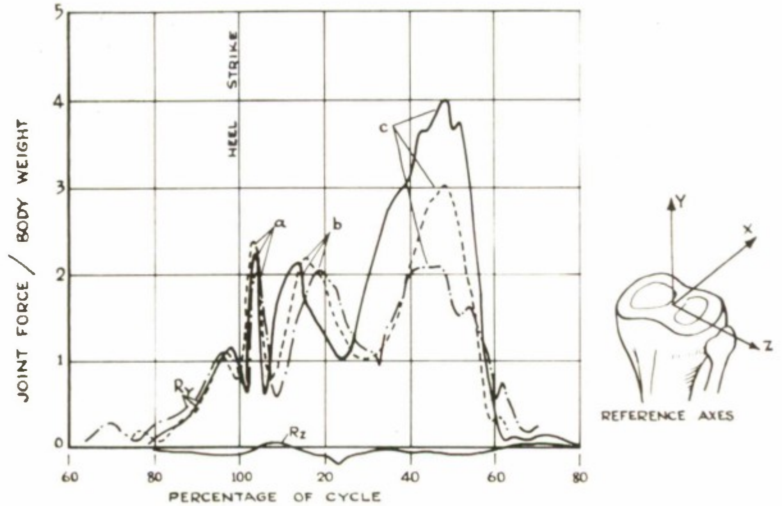

FIG. 6. Joint Force at Knee-Level Walking.

Test No. 11 ———; 2 - - - -; 13 —·—·—·—

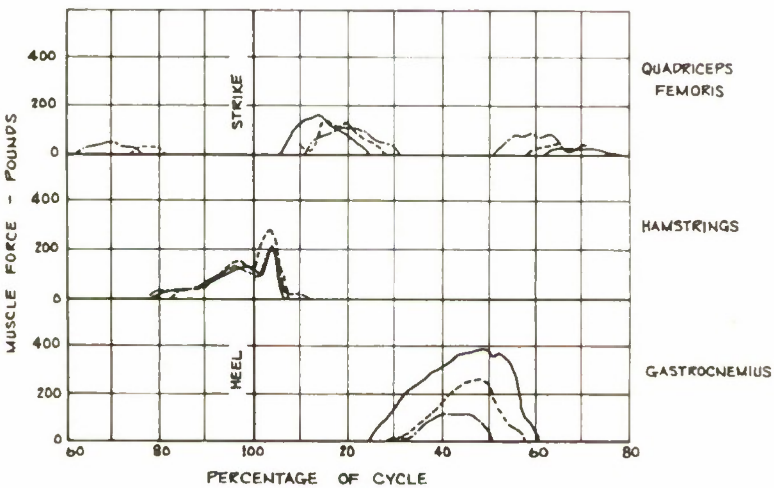

FIG. 7. Muscle Force-Level Walking.

Test No. 11 ———; 2 - - - -; 13 —·—·—·—

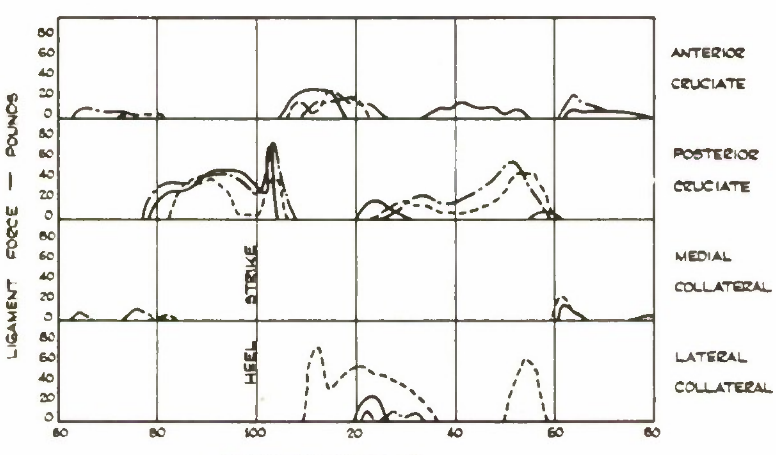

FIG. 8. Ligament Forces during Level Walking.

Test No. 11 ———; 2 - - - -; 13 —·—·—·—

(1941). Following heel strike the knee is subject to a moment, $+M_{zs}$, i.e. a tendency to flex the joint, and force action in the quadriceps femoris resists this moment and controls the position of the knee. In the second half of the stance phase, force action in the calf muscles causes plantar flexion of the ankle and hence produces forwards acceleration of the body and a corresponding anteriorly directed force acting at the foot. Moment, $-M_{zs}$, acting at the knee tends to extend the joint and is resisted by the action of gastrocnemius. Being a biarticular muscle the gastrocnemius both stabilizes the knee and produces plantar flexion of the ankle (assisted by soleus). At toe-off force action in the quadriceps femoris imparts a forwards acceleration to the leg.

It should be noted that in calculation of the force values acting in the hamstrings it was assumed that there was no assistance of this muscle group from the gracilis or sartorius muscles. Gracilis is mainly an anductor of the hip and its line of action affords it little leverage at the knee in comparison to the hamstring muscles. Sartorius, also having less leverage than the hamstrings, is a relatively weak muscle. It is reasonable to assume therefore that the components of moment, $-M_{zs}$, transmitted by these two muscles are of a minor nature and the error introduced by assuming the hamstrings group to be the sole flexor of the joint is small. The same argument may be applied to justify the assumption of the quadriceps femoris as the sole extensor of the knee, which neglects the assistance of tensor fasciae latae.

(2) *Forces in the ligaments*

The magnitude and phasing of the forces calculated in the ligaments is shown in Fig. 8. Maximum force recorded in the cruciate ligaments of the 12 subjects varied from 10 to 112lb. In all tests the posterior cruciate carried the greater force, mean maximum force being 74 lb. compared with 35 lb. in the anterior cruciate. In calculating these forces the effect of friction was neglected. A friction force between the articular surfaces acting in the anterior or posterior direction may either increase or decrease the force required in the cruciates depending on the direction of rota-

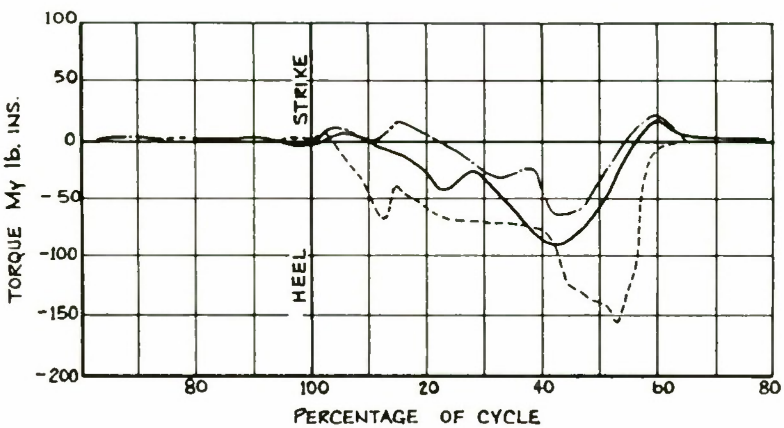

FIG. 9. Torque M_y acting at Knee Joint during Level Walking.

Test No. 11————; 2 - - - -; 13 —·—·—·—

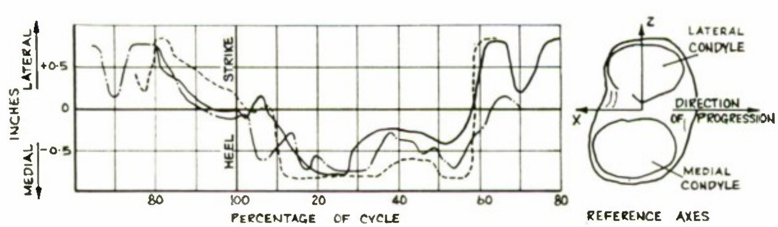

FIG. 10. Position of centre of pressure Z_0 on Condyles during Level Walking.

Test No. 11————; 2 - - - -; 13 —·—·—·—

tion of the femoral condyles on the tibia. Assuming a value of 0·02 for the coefficient of friction in the joint, friction forces would have a maximum value of the order of 9 lb., this force corresponding to the position of maximum joint force in the walking cycle.

Forces calculated to act in the medial collateral ligament were small, having a maximum value of 29 lb. Forces transmitted by the lateral collateral ligament were much greater, having a mean maximum value of 59 lb., and a maximum value of 148 lb. These forces were developed to prevent adduction at the knee during the stance phase of walking.

According to the literature surveyed (Brantigan and Voshell, 1941; Gray's Anatomy, 1962: Eds. D. V. Davies and F. Davies), part of the reaction required to resist abduction or adduction may be transmitted by the cruciates. The experiments of Brantigan and Voshell (1941) show that when the knee is in extension the collateral ligaments are capable of preventing movement in this direction, no instability occurring when the cruciates were severed. In flexion, however, due to the slackening of the lateral collateral, absence of the cruciates resulted in increased instability of the joint. This would indicate that the assistance of the cruciates in checking abduction or adduction is more significant in positions of flexion. From a mechanical point of view the collateral ligaments are best situated to resist abduction and adduction and, provided there is no initial slackness in the ligaments, there must consequently be more strain in the collateral ligament resisting movement than in the cruciates. The large forces calculated to be acting in the lateral ligament occurred in the stance phase of walking and hence at positions of the joint in which this ligament would normally be taut. It is deduced therefore that in walking the collaterals rather than the cruciates provide the major reaction to moments of abduction or adduction acting on the joint.

With regard to forces calculated in the lateral collateral, it should be noted that the forces ascribed to this ligament for the purpose of analysis will most likely be carried partly as tension in the ilio-tibial tract. The distribution of force between these two elements could not be determined from the information available. It may also be possible that the large adduction force acting on the joint during the stance phase is partly equiliberated by differential action of the lateral and medial hamstrings or of the lateral and medial heads of gastrocnemius. At present however there is no experimental evidence to support this theory. It has been suggested by several authors that tension receptors in the articular ligaments, when activated, instigate a reflex contraction in the muscles capable of protecting the particular ligament. This hypothesis is suggested in relation to the ligaments of the knee joint in particular by Smillie (1946). Experiments by Stener (1959) investigating the medial collateral ligament of the knee joint contradict this hypothesis.

Figure 9 shows an increasing inward torque, $-M_{yx}$, acting at the knee during the stance phase of walking. Moment action, M_{yx}, about the long axis of the tibia must be balanced mainly by force actions in the ligaments and will alter the distribution of ligament forces calculated in the analysis. From mechanical considerations the oblique posterior fibres of the medial collateral ligament would be most favourably placed to resist the inward torque shown in Fig. 9, and it is suggested that the greater part of the torque acting at the knee will be balanced by tension in this ligament. Tension in this ligament required to produce equilibrium would not significantly increase calculated values of joint force as force in the posterior cruciate, which is also in tension at this part of the cycle, would tend to be reduced in order to maintain equilibrium of forces in the anterior-posterior direction.

(3) *Forces transmitted by the articular surfaces*

Joint force results presented in Fig. 6 represent the tests in which the greatest, average and smallest values of maximum joint force, R_y, were obtained. The three main peaks in the joint force curve, referred to as peaks *a*, *b* and *c*, in Fig. 6 correspond to the peaks of muscle force shown in Fig. 7.

For the 12 subjects tested the average values of peaks *a*, *b* and *c* were 2·43, 2·23 and 2·72 times body weight respectively. Maximum joint force measured varied between 2·06 and 4·0 with an average value of 3·03 times body weight. Variations in peak values of joint force and their phasing in the walking cycle shown by different subjects are considered by the author to be due partly to anthropometric differences between subjects and partly to differing characteristics in the gait of the subjects. Where a subject was tested twice, the joint force curves obtained from the two tests bore close

comparison, the magnitude of the three peaks and the percentage of the walking cycle at which they occurred being in good agreement.

Tests on male and female subjects revealed no obvious differences in the magnitude or cyclic variation of joint force between the sexes. In Figs. 6 - 10 tests 11 and 13 represent the results obtained using female subjects and test 2 represents the results obtained using a male subject. From the results of the 14 experiments conducted it would appear that variations in joint force within the sex groups, due possibly to anthropometric factors and individual gait characteristics, are greater than any variations between the sexes due to anatomical differences.

The side or shear force, R_z, (measured as a fraction of body weight) acting on the condyles is shown in Fig. 6. Due to its relatively small magnitude in this graph, the curves of three subjects could not be superimposed clearly and only the curve of one subject is therefore shown. Mean maximum value of R_z calculated for the 12 subjects was 0·26 times body weight.

Experimental results of all subjects indicated that during the stance phase of walking the centre of pressure was positioned over the medial condyles, as shown in Fig. 10. It therefore follows that the greater part of the joint force was transmitted by the medial condyles at this part of the cycle. The above statement is at variance with the commonly held belief that the greater load is transmitted by the lateral condyles. Steindler (1955) states that the greater amount of pressure is borne by the lateral condyles ' because of the obliquity of the anatomical axis of the femur '. It is maintained by the author that the obliquity of the axis of the femur cannot possibly affect the force system acting at the knee joint, and consequently the distribution of pressure between the condyles. The force system acting at the knee is dependent, rather, on the position of the centre of gravity of the body and the external forces acting upon it. From a mechanical point of view, a greater portion of the force transmitted by the medial condyles as opposed to the lateral condyles would be structurally more favourable for the following reasons: as the medial condyle probably has a larger bearing surface, the compressive stress at the articular surface would be lower; as the medial condyle overhangs the shaft of the tibia less than the lateral condyle, the stresses acting in the shaft of the tibia would be less.

Summary of Results

(1) Maximum joint force calculated at the knee during walking was in the range 2 - 4 times body weight, the average value of 12 subjects being 3·03 times body weight.

(2) When the joint was highly loaded, the greater portion of the load was transmitted by the medial condyles.

(3) Forces acting on the joint in the mediolateral direction were generally small. Their mean maximum value was calculated to be 0·26 times body weight.

(4) The mean maximum forces acting in the anterior and posterior cruciate ligaments and the medial and lateral collateral ligaments were 35, 74, 14 and 59 lb. respectively.

(5) The greatest muscle force calculated was 405 lb. For the 12 subjects tested the average values of maximum force developed in the quadriceps femoris, hamstrings and gastrocnemius muscle groups was 167, 270 and 234 lb. respectively.

(6) No significant difference was apparent between the joint forces calculated for male and female subjects.

(7) It is essential that the values quoted above are interpreted in relation to the assumptions made in defining the mechanics of the knee joint. The limitations of the analysis in determining the true value of these quantities are discussed in detail with the presentation of results.

Knowledge of the force values transmitted by the joint tissues is of importance in the further development of reconstructive joint surgery, in the design of mechanical components for partial or total joint replacement, and in the understanding of joint lubrication. It is hoped that the work described in this paper will contribute to the solution of problems in these areas and also to the general understanding of the mechanics of the knee.

Acknowledgements

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TECHNICAL NOTES

Glass Capillaries for Gas Chromatography

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Introduction

Gas chromatography in its simplest and most usual form uses columns of the order of 2 - 3 metres long by 2 - 4 mm diameter. The columns are packed with an inert material which carries the stationary (active) phase. The chromatographic separation takes place by a process of successive adsorption and desorption along the walls of the channels formed between the particles of the packing. Resolution is improved by increasing the length of packed columns until the point is reached at which the differences in the lengths of the micro channels between the particles becomes the resolution determining parameter. In practice no improvement is obtained with columns longer than about four metres. Very great improvement in resolution can be produced by the use of capillary columns of about 0·25 - 0·5 mm bore and up to 100 metres in length. Here the stationary phase is coated on the walls of the column, no packing is used and hence only one channel is available for separation to take place.

Materials and Quality of Capillary

Long capillaries are prepared from suitable tubing materials by cold and hot drawing. Cold drawing metal—hot for glass. In this way lengths of up to 30 metres for steel and 100 metres for glass can be obtained. The material must of course be basically suitable for production of capillaries as it is essential that the internal diameter finally achieved must remain constant under prevailing conditions of temperature and pressure. This severely limits the application of materials. The surface must be smooth or at any rate should have no roughness of more than about 0·001 mm. The internal surface should not be disfigured by deep furrows from irregular drawing or by oxide layers as for iron, copper, brass or aluminium or metal particles which have been pressed into the surface. Further, the type of surface used must allow the formation of an even and thin film of stationary liquid phase.

The pressure drop of the carrier gas for a given flow rate depends on the linearity of the length of the capillary but varies with the diameter stability is outstanding and so is of the capillary produces almost as great a pressure drop as if the whole capillary were of that diameter.

Pressure drop and rate of analysis, internal diameter and ease of coating or cleanliness of the capillary are thus closely connected. Materials such as glass produce good capillaries with lengths up to 100 metres or more, with the advantage that it can be easily worked with the right apparatus (see Fig. 1) and long lengths of regular dimensions may be obtained. The diameter stability is outstanding and so is the quality of the internal surface which has sufficient degrees of smoothness and good wetting properties for polar and non-polar liquids.

Apparatus

The apparatus shown in Figs. 1 and 2 was built at the Admiralty Oil Laboratory based on an original design by Desty[1], and successfully draws capillaries up to 100 metres or more in length, winding the capillary into a compact coil for ease of handling.

The apparatus shown is mounted on a sheet of asbestos of suitable thickness, the thick

walled glass tubing used as a starting material is 7 mm o.d. × 3 mm i.d. and is transported by rollers 1 and 2. Roller 1 has a diameter of 36 mm and is driven at a constant rate by an electric motor but its speed can be adjusted up to a value of 10 revolutions per hour. Roller 2 presses the tubing with sufficient degree of firmness against Roller 1. The glass tube is then driven at a suitable speed through the heater or furnace. This consists of a nickel strip 12 in. long, ¼ in. wide and 0·024 in. thick, wound into a helix of about three turns and ½ in. diameter.

The furnace is clamped in a horizontal position at the same height as the glass tubing and is heated electrically from a low voltage transformer with an output of five volts at 100 amperes which can be adjusted by a variac on the primary side of the transformer. The helix must be run at bright red heat for boro-silicate glass. The capillary formed by the heater is transported by the pair of rollers 4 and 5, roller 5 can be adjusted between 60 and 300 revolutions per hour. The straight drawn capillary travels at the rate of a few mm per sec. into a steel tube of about 2·2 cm long and 6·5 mm o.d. 5·0 mm i.d. which runs straight for about 6 in. and then is bent into a half circle of 5 in. diameter as shown in Fig. 1. The tube is fixed in such a way that the straight entry is level with the drawing rollers and the curved part is uppermost. At certain points the steel tube is provided with electrical connections. These are connected to a low voltage transformer.

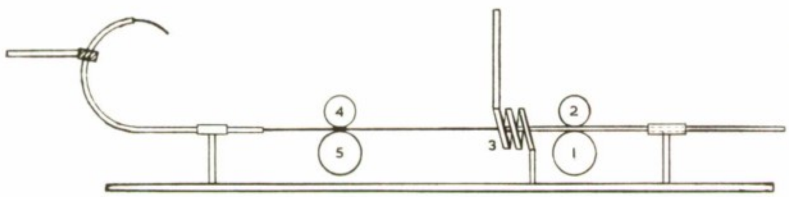

FIG. 1. Schematic of Capillary Apparatus.

Rollers—1, 2, 4, 5.
Heater—3.

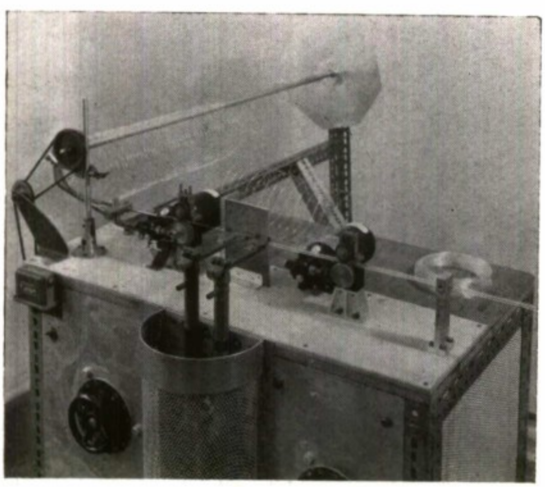

FIG. 2. General view of Capillary Apparatus.

The steel tube is continuously heated to a dull red heat so that the capillary pass through it just softened and bent into the arc of the steel tube and so into a helix. This helix is then taken up by a long smooth revolving tube which runs at right angles to the direction of drawing. The process is started by taking a glass tube drawn out to a short piece of capillary at one end and feeding through the heater and into the draw rollers. The heater is switched on and after a sort time the feed and draw rollers are started. The draw speed is adjusted according to the desired dimension of the capillary. The length of the capillary is found by counting the coils on the guide rod. Once the apparatus has been set in motion it will continue without further adjustment. An initial tube length of 5 ft., 7 mm o.d., 3 mm i.d., will be drawn into a capillary length of approximately 30 metres in about two hours.

Greater lengths of capillary may be obtained by fusing a further length of glass tubing into the apparatus while the process is in operation.

Acknowledgement

The author would like to thank the British Petroleum Co. Ltd. for their assistance in adapting this apparatus for A.O.L.'s requirements.

Reference

(1) Desty, D. H., Haresnape, J. N. and Whyman, B. H. F. *Analyt. Chem.*, **32** (1960) 302.

A Reliable Gland for Rubber Cables

Admiralty Research Laboratory

A high pressure gland for sealing watertight equipment at the cable entrance has been developen from the traditional "mining gland".

The ARL gland was designed for applications in which many units are connected in parallel in an underwater junction box, with the requirement that failure of one cable would not flood the junction box. The mining gland (Fig. 1) was inadequate for this requirement.

The rubber bung has been retained as a first line of defence against the water pressure. The gland nut pressurises the bung via a tanged washer and a barrel washer. The tanged washer prevents rotation of the components and the barrel washer allows for misalignment of the parts. The novel parts of the gland are the seal cover, seal plate and associated "O" ring. (Fig. 2). These parts together form a positive barrier between the equipment and water flow along and through the cable.

The seal plate is fitted with an appropriate number of feed-throughs, which may be Corundite or metal-glass seals soldered in position. The feed through can also be a pin or socket, to make a watertight plug and socket assembly. The plate has an "O" ring groove and the cable side is threaded to receive the seal cover. A hole is provided in the seal cover for resin filling, which must not be too viscous when the cover is well filled with cable.

The gland body bore at the seal plate end must have an "O" ring finish. The slight increase in manufacturing costs being more than compensated by the increased reliability. This gland has withstood tests at pressures as high as 3000 lbf/in.^{2} (20 MN/m^2) without any ill effects. The conventional mining gland failed at 500 lbf/in.^{2} (3 MN/m^2), the cable being extruded.

Cables glanded have varied from 0·25 in. (6 mm) dia. single core up to 1·5 in. (38 mm) dia. single core cable rated at 5 kV r.m.s. 20 amp, and multicore cables containing up to 13 cores. The glands have been in service for eight years in 20 - 30 fathoms (36 - 55 m), and some have been used in deeper water. No gland has yet failed in service.

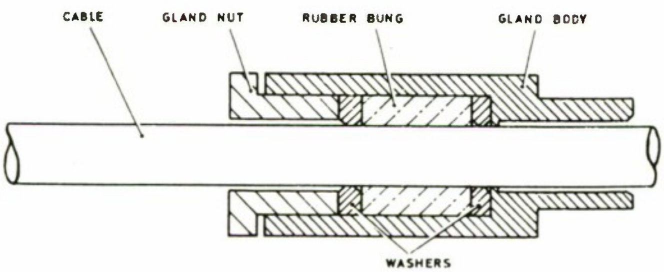

FIG. 1. Section of a typical "Mining" Gland.

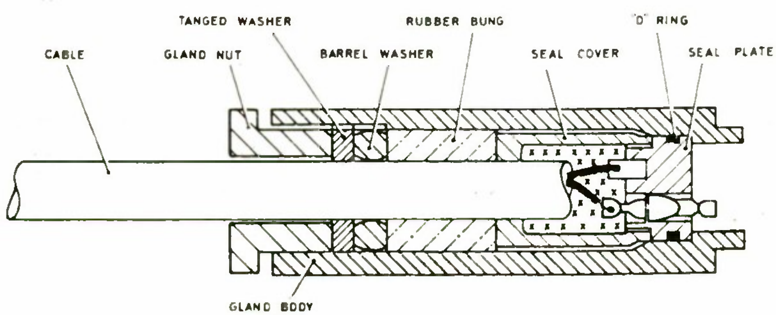

FIG. 2. Section of a typical ARL Gland.

PROMISING AREAS FOR UNIVERSITY WORK ON FRACTURE IN ENGINEERING MATERIALS

Abstract

Over the past few years there has been a number of catastrophic structural failures involving ships breaking in two, the collapse of storage tanks and bridges as well as pressure vessels failing under test.

Investigation has identified these failures with a phenomenon known as Brittle Fracture and the following statement is issued on behalf of the Navy Department Advisory Committee on Structural Steels.

Introduction

The purpose of this note which originated from discussions within the Collaborative Research Working Group of the Navy Department Advisory Committee on Structural Steels is to draw attention to the continued need for university research into topics associated with the prevention of fracture, and to suggest particular aspects for detailed study that could produce results of great value to the engineering industries of this country. These comments arise from discussion between representatives of the pressure vessel, structural engineering and shipbuilding industries, the steelmaking and fabrication interests and specialists in the field of failure prevention of welded steel structures. The emphasis of their comments thus is primarily towards the present limitations of understanding in fracture behaviour of such structures; it must be stressed that much of the basic work will be relevant also to fracture in plastics and other non-metals, as well as to the development of newer materials such as composites of different types. The suggestions are made in general terms to enable interested workers the maximum scientific freedom of approach: the NDACSS Working Group on Collaborative Research would, however, be very willing to discuss individual proposals in detail. They would also be willing for individual workers to attend appropriate meetings of the Collaborative Research Working Group to hear the background and to discuss their results if appropriate.

General Problem

Over the last few decades there has been an outstanding growth of understanding of the basic factors controlling fracture, so much so that it could well be questioned whether further basic work is needed. The continued occurrence of the occasional dramatic failure of welded structures such as bridges, pipelines, ships and pressure vessels highlights the fact that there is still a practical problem, which is made more severe with every extension of present practice to higher stress levels, thicker sections and less conventional materials. In many cases the detailed nature of the failures are inexplicable, and the measures taken to prevent such failures are clumsy, broad-based and expensive. For example, ignorance of what are the proper fracture toughness criteria leads to excessive demands and pessimistic tests that add expense to the material, the design and the fabrication. The standards of rejection for

defects are subjective, rather than based on a real understanding of what defects can be tolerated, again adding expense and danger of failure from rectifications.

Even so the occasional failure occurs, frequently with extensive delay to some major plant, with consequential losses that may run into millions of pounds. The present situation is perhaps best illustrated by the fact that current engineering design is based almost entirely on the criterion of gross change of shape, using elastic or plastic limit treatments whereas in reality service failures almost always occur from fast fracture at defects either initially present or produced by corrosion, creep or fatigue. Realistic economic design and material development will only follow from as good an understanding of fracture as is the present understanding of elasticity and plasticity.

Specific Problems

The biggest difficulties in the quantitative treatment of fracture unfortunately occur with the most widely used structural material—low strength steel. Whilst considerable progress has been made with respect to understanding the fracture in brittle solids, and even in those higher strength steels which show fracture from a defect under almost elastic conditions, there are still major limitations to our theoretical understanding of the conditions that lead to failure where considerable deformation procedure fracture, and in particular of the mathematical treatments available to analyse the conditions around a defect where there is considerable plasticity. The growing success of finite element analysis gives considerable promise on this problem, but much more work preferably enabling more simple use of the results, will be necessary to provide a real working tool. Such work would be essential before a general theory of fracture mechanics for conditions involving plasticity can become as developed as the linear-elastic fracture mechanics now found so valuable for more brittle conditions. It would need to cover variation in strain-hardening exponent, and to be extended to high local strains before failure, merging into a treatment based on instability analysis.

In the absence of detailed elastic-plastic stress analysis around stress concentrations, general yield fracture mechanics have been based on a crack opening displacement treatment. This has shown considerable promise for simple geometries, but further work is needed to establish the analytical and experimental techniques for the complex stress-concentrations that occur in many engineering structures.

Another major difficulty with structural steels is the variation in their properties with change of strain rate, with a consequent difference in behaviour between static crack initiation and crack propagation. More detailed understanding of these differences and of the effect of engineering structure on propagation behaviour could lead to more appropriate design and assessment techniques.

Finally, it is most important to stress that the engineering structures concerned are almost entirely welded structures and it has been said that some 90% of the failures of such structures are associated with the welds. Whilst it is known that welding changes, and usually reduces the fracture toughness of steel plate around the weld (especially if there are notches or defects near the weld), the metallurgical factors controlling the magnitude of this change are not well understood. Working, leading to the development of structural steels showing less weld damage, could be of major economic importance. Detailed study of the effect of thermal treatment on the recovery from weld damage would also be valuable, not only in defining appropriate treatments but in development alloys with good final properties, or with good response to minimal treatments. This work also requires a better understanding of the instantaneous temperature/strain patterns around defective joints throughout welding by different processes, a problem suitable for both mathematical and experimental treatment.

Another important practical aspect of this problem which would benefit from theoretical treatment is to estimate the importance of local regions of brittleness in an otherwise tough structure.

Returning to the general problem of fracture, the present understanding of the relationship between micro- and sub-micro-structure and fracture toughness is only known in general terms, and appears not to be developed to the same state of knowledge of the similar relationship to strength. This is important since it hampers the development of fracture-tough materials, and further work on this relationship, or the indirect relationship via other fundamental properties would provide a study of long term interest.

Summary of Specific Proposals

(a) *Mathematical*

(1) Improved mathematical treatment of condition around a notch with considerable local deformation, including study of the effect of strain hardening exponent and assessments related to crack opening displacement approach.

(2) Simplified methods of handling elastic-plastic problems of (1) e.g. automatic plotting devices.

(3) Determination of COD/stress relationships in complex geometries.

(4) Calculation of temperature/strain/time patterns near a notch and weld during fabrication.

(b) *Mechanics Aspects*

(1) Effect of strain-rate on fracture criteria.

(2) Calibration of COD/stress in difficult geometries.

(3) Experimental determination of stress/strain/time patterns near welds during fabrication.

(4) Derivation of acceptable defect size in engineering structures.

(5) Study of the effect of local brittle regions on the behaviour of an otherwise tough structure.

(6) Study of the effect of creep and fatigue on eventual failure behaviour.

(c) *Material Aspects*

(1) Detailed study of effects of micro- and sub-micro-structure on fracture toughness.

(2) Effect of alloy composition and structure on the reduction in fracture toughness near a weld due to welding and on the recovery in toughness by thermal treatment.

(3) Associated with (2), detailed study of factors controlling the magnitude of strain aged and precipitation-induced changes in fracture toughness.

Letter to the Editor

Dear Sir,

While on holiday in Western Canada my wife and I paid a visit to Sir Charles Wright who is enjoying a well earned retirement on Salt Spring Island near Vancouver, and I feel sure many of his old friends in the R.N.S.S. would be interested in his latest activities.

As we approached Fulford Harbour, on the ferry from Victoria, the sun was setting behind the southern headland of this enchanting semi-tropical island, giving a picture of peaceful serenity. Motoring from the south to the north the roads became narrower and finally changed into a rough track as we turned into Arbutus Road, named after the beautiful trees which are a feature of the locality. A letter box marked " Wright " showed that the home where Sir Charles and his daughter live was somewhere among the trees.

The bungalow is on the cliffs at the extreme northern end of Salt Spring Island, overlooking a beautiful quiet backwater with a wonderful view of Vancouver Island beyond the Stuart Channel dotted with other small gulf islands. As we sat on the balcony talking of old times, the sunset and the red glow of the sky was enhanced by the red glow of the Arbutus trees, which Sir Charles had illuminated with floodlights. He designed the bungalow and is still making improvements himself even when he has to chop down pine trees to do so. The great difficulty is lack of water, and, in spite of the use of a water deviner and workmen who have bored down 300 ft, no water has yet been found. Consequently water for their modern bathroom and kitchen has to be carted in 40 gallon drums a considerable distance from St. Mary's Lake by Sir Charles, aided by his daughter. Not only are Sir Charles and his daughter doing their laborious chores themselves, he is also constructing a complete workshop in which he hopes to build a boat, while his daughter paints beautiful animal pictures for book illustrations. He is also hoping to do all the scientific writing he has not had time for before. Propped up against the workshop was an old pair of skis, an historic reminder of weeks of ploddng across the Antarctic with the Scott expedition. His work is still remembered for yet another medal arrived from the U.S.A. while we were there.

He now explores his island and took us to see the view from the highest point; a view of the surrounding countryside covered in coniferous and Arbutus trees interspersed with banks of flowers, some unknown in Britain but including vivid pink and white foxgloves. This is an idyllic place for an active man of 83 to live in retirement and we hope he enjoys it for many more years. As we bade farewell to the Wrights, Sir Charles's words were " *Remember me to the boys* ", a message which I am now passing on through this journal.

A. Butterworth

NOTES AND NEWS

Admiralty Surface Weapons Establishment

The Defence Scientific Advisory Council visited the establishment on 6 May and were given a review of the establishment's organisation and purpose and detailed presentations of several major aspects of current work. The establishment's Library was included in the Spring Study Tour of the College of Librarianship (Wales).

Mr. M. Bates, Scientific Assistant, was presented with the Imperial Service Medal by the Director on 4 June.

Mr. N. A. Godel, P.S.O., left the Assessment Division in February to attend the Senior Officers War Course.

Mr. A. H. G. Oberman, S.E.O., has returned after being seconded for two years with the Western Pacific High Commission of the Ministry of Overseas Development in the Gilbert and Ellice Islands. He was in charge of the Radio Section of the Post and Telecommunications Department.

Mr. H. E. Hogben, S.P.S.O., returned to the Establishment for de-briefing after holding the post of Scientific Adviser on the British Navy Staff in Washington D.C. He retired from the R.N.S.S. on 15 May 1970.

Mr. W. R. Joy, S.P.S.O., has replaced Mr. G. A. Halnan as one of the Assistant Directors of Naval Physical Research in M.O.D.(N), London. Mr. Halnan has returned as Head of the new Planning and Resources Division.

Mr. J. W. Snowdon, S.P.S.O., became S.S.P.(N) on 6 February 1970.

Mr. K. A. G. Taylor, P.S.O., relinquished his post as Workshop Manager on 2 March 1970 to join S.S.P.(N).

Mr. B. O. Penny was transferred to S.S.P.(N) on promotion to C.E.O. on 6 April 1970.

Mr. D. McArthur was transferred to D.N.R.D.A. on promotion to P.S.O.

Dr. J. Croney, D.C.S.O., has been appointed as a visiting Professor in the Faculty of Electronic Engineering at Southampton University.

Linn Ratsey retired on 29 May 1970 after 33 years' service in the cause of Naval science. His career covered an exceptionally wide range of experience, and proved that, so long as a man understands clearly and remembers the basic scientific principles, he can be creative in widely diverse applications.

He joined H.M. Signal School in 1937 as a J.S.O., and did pioneering work on radar. He specialised during the war years in radar transmitters and modulators, and in particular in the use of gas discharge tubes for short pulses. But he also took a strong interest in all aspects of radar techniques and made many contributions outside his own field.

In June 1940 he invented the discharge-line square-pulse modulator for application to the magnetron transmitters then appearing. For this he received, in 1951, one of the financial awards for ‘ Inventions that helped to win the war ’. He also shared in another Award, for proposing goniometer phase-shifting for accurate ranging in gunnery radars.

His radar work started at Eastney, then two years at Onslow Road, Southsea, followed by the evacuation to Witley, and after the war some three years at Waterlooville as Head of the A.S.R.E. Research Group. In 1949 he became Head of the Gunnery Radar Division GX at Witley, and moved with them to Portsdown Block 3 in mid-1951. For much of that time he was working with frequencies of 3,000 and

10,000 MHz. It was therefore a dramatic change that followed when he transferred to U.C.W.E. at Havant in 1954 to work on mining problems involving frequencies of a fraction of a Hz.

At that time the mining threat was causing a stir, and Linn Ratsey went to reinforce the team at U.C.W.E. They became nicknamed " the decibel boys ", with Linn himself dubbed " the arch decibel ".

In 1959 he moved to Portland with U.C.W.E. under the " Way Ahead " scheme for the amalgamation with U.D.E. and the Torpedo Experimental Establishment to form A.U.W.E. At the same time A.G.E. moved from Portland, joining up with A.S.R.E. to form A.S.W.E.

In March 1961 Linn Ratsey was promoted to D.C.S.O., and rejoined A.S.W.E. as Head of the Communications and E.W. Department. In this capacity he became involved in the introduction into the Fleet of such techniques as frequency synthesizers, single side-band working, auto-telegraphy, on-line encryption, underwater reception of V.L.F., and so on. This continued until he retired from that post in October 1968, but since then he has concentrated, as a dis-established S.S.O., on H.F. Sounding: it is expected that good use will be made of his work in this field.

Linn Ratsey is gifted with one of the most versatile and original of minds, and always insists on reasoning from the basic scientific principles. He is also blessed with the sharpest tongue in the Scientific Civil Service, and has used it to good effect in deflating the pompous or the careless, and in pungent and penetrating remarks that stimulate other people to think.

He has always been interested in people, and has played a very full part in the social activities of the establishments in which he worked. He played hockey, tennis and cricket of a high standard. He became Chairman of the A.S.W.E. Sports Club in 1961, and has been asiduous in attending its activities. He made a point of mixing with as many people as possible at all the social functions.

Linn Ratsey was never one for nostalgic memories of past achievements, but has always looked forward to the future. His first task in retirement is to polish up his knowledge of Italian, and teach English on an " au pair " basis to an Italian family in Sicily. He has then agreed to write up the history of Naval radar development in the war years. His other outside interest in music will always keep him busy.

As a token of the affection and respect in which his colleagues hold him, the Director presented him with a typewriter, a barometer and an R.N.S.S. crest.

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Arthur Lambert retired on the 15th July 1970 after almost 45 years of service to the Admiralty.

It was his intention when he left school to follow in his father's footsteps and serve in the Royal Navy. In pursuance of this ambition he joined H.M.S. *Fisgard* as an electrical artificer apprentice in August 1925 but due to an unfortunate accident during training he was unable to continue in the service and was transferred to EEM department at Portsmouth Dockyard where he completed an electrician apprenticeship in 1930.

He qualified in the Civil Service draughtsmans examination and was appointed to H.M. Signal School in October 1935. Service continued at the Admiralty Signal Establishment and during the war he was evacuated to Haslemere. Promotion to Senior Draughtsman came in 1946. The Admiralty Signal and Radar Establishment was built and Mr. Lambert returned to Portsmouth where he was promoted to Chief Draughtsman in 1952.

The " Way Ahead " programme was carried through in 1959 and the Establishment became the Admiralty Surface Weapons Establishment combining staffs of ASRE, UCWE and AGE, and Mr. Lambert became the Head of Drawing Office. In 1968 he was appointed Drawing Office Manager which post he held until retirement.

In making a presentation to him the Director, Mr. H. W. Pout, paid tribute to Mr. Lambert's long and devoted service to the Admiralty and wished him a long and happy retirement.

Admiralty Underwater Weapons Establishment

A recent addition to the facilities at A.U.W.E. is a new electronic workshop comprising two floors of approximately 64 ft. by 36 ft. upper, and 39 ft. by 26 ft. lower. The upper section, where the electronic work is carried out is air conditioned and temperature controlled, and lighting is in the region of 900 lux. On the lower floor is a small well-equipped mechanical workshop.

Electronics Workshop

Apprentices from the U.K. Atomic Energy Establishment Winfrith visited A.U.W.E. on 24 March. The guests were entertained to lunch, given an introductory talk and a film, and toured the Apprentices Training Centre and workshops. Next came the annual soccer match for the Longley Challenge Cup, which was retained by A.U.W.E. for a further year by a good 3 - 2 win. The visit was rounded off by a skittles match at a nearby hotel.

On 29 May Mr. A. E. Williams presented a Torpedo Assessment Case Study to the Military Operational Analysis Course at the Royal Military College of Science, Shrivenham.

Mr. R. Scholey of the Materials Division attended the International Symposium of Underwater Technology held at the Royal Netherlands Naval College, Den Helder on 10 and 11 June.

A party of 30 members from all Directorates in the Weapons Department at Bath visited A.U.W.E. on 10 June to see something of the establishment, its work and the people at the other end of the telephone line.

The Imperial Service Medal has been awarded to Mr. H. A. Longyear, Scientific Assistant (disestab.) of A.U.W.E., in recognition of 45 years' Admiralty service. He commenced this service in Portsmouth Dockyard in October 1925, and has spent a large part of his career on trials of underwater equipment, and continues to serve in this field. The photograph shows Dr. R. Benjamin (right) congratulating him after the presentation.

(Photograph by courtesy of "Daily Mirror")

Sue Kingman, Clerical Assistant of A.U.W.E., was among eight young people who were the first of 65 prizewinners in the *Daily Mirror* Youth Sailing Competition. Their prize was a week's cruise to France, Belgium and Holland in the Ocean Youth Club's 57 ft. Bermuda Ketch *Sir Thomas Lipton*. None had any previous experience at sea, but under the watchful eyes of the skipper and mate, the only permanent crew members, they quickly mastered the rudiments of handling the sails and working ship, and arrived weary but happy at Brightlingsea, Essex on 7 June.

Central Dockyard Laboratory

Dr. E. N. Dodd, Superintendent Scientist, attended an International Seminar on Water Pollution by oil which was held at Aviemore from 4 - 8 May.

Dr. Dodd and Mr. Houghton attended the Seventh Plenary Session of the Comite' International Permanent pour la Recherche sur la Préservation des Matériaux en Milieu Marin, held in Madrid on 26 - 29 May.

As Chairman of the M.O.D.(N) Working Party studying the ultimate fate of oil at sea, Dr. Dodd attended a trial at the beginning of June in the Western Approaches when several hundred tons of crude oil were released and the subsequent oil slicks studied and sampled over a period of time. The trials party included staff from A.M.L., A.O.L., Marine Biological Laboratory, Plymouth, N.I.O., M.A.F.F., and the Institute of Petroleum, and was accommodated on board R.F.A. *Tidepool*. Assistance was also provided by R.N.A.S., Culdrose in the provision of Wessex V helicopters, by R.A.F. St. Mawgan who supplied daily aerial observation, and by Devonport Dockyard which made available the ocean-going tug *Samsonia* to assist in the oil and water sampling.

C.D.L. has contributed to the Naval Materials Conference at R.N.E.C. Manadon, 1 - 3 July, by way of a joint paper with A.M.L. and S.A./D.G.S. Specimens showing cladding techniques and dissimilar metal joints were exhibited.

Mr. W. R. Weaver, in collaboration with Mr. H. A. Hipwood of Q.A.D. (Mat.), Woolwich, has published a paper entitled "A proposal for the adoption of the British Standard Artificial Weathering Test by I.S.O." in the May 1970 issue of the *Journal of the Oil and Colour Chemists' Association*.

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Co-ordination of Valve Development

Mr. M. Hillier visited the U.S.A. during May 1970 for a meeting of T.T.C.P. J5 Panel at Night Vision Laboratories, Fort Belvoir and Sub-Group J meeting at Naval Underwater Centre, Pasadena. He also had discussions at the Institute for Defense Analyses, Washington D.C.

Mr. L. N. Large visited France from 27 to 29 May 1970 to attend a meeting of the Anglo-French Acoustoelectric Consortium held in Nice. The opportunity was also taken to visit Texas Instruments Ltd., at Cagnes sur Mer.

The next CVD Dinner is being arranged for Wednesday, 14 October 1970 and by kind permission of the Admiral President will be held in the Painted Hall, R.N. College, Greenwich. Further details may be obtained from Mr. J. McCarthy, Empress State Building (01 - 385 1244) extension 2765.

The C.V.D. Office moved from Old Admiralty Building, Whitehall to the Empress State Building, Earls Court on 3 July 1970.

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Services Valve Test Laboratory

Mr. H. Lewis attended the 35th International Electrotechnical Commission General Meeting in Washington on 25th to 29th May 1970, as Chairman of Technical Committee No. 39—Electronic Tubes and its Technical Working Group No. 1 on the International Vocabulary for electronic tubes.

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ROYAL MARITIME AUXILIARY SERVICE

The Royal Navy's various ocean-going support and auxiliary ships, other than those of the Royal Fleet Auxiliary, have been amalgamated into a new service to be known as the Royal Maritime Auxiliary Service (RMAS).

The new service, under the administration of the Director of Marine Services (Naval), will comprise research and development ships used by the Navy Department, the ocean towing fleet, a number of mooring and salvage vessels, cable ships, *etc*.

When the current new construction program is completed the RMAS will comprise about 50 vessels ranging from a few hundred tons to over 3,000 tons. RMAS ships will have black hulls and boot topping with grey upper work and funnels. They will wear blue ensigns defaced in the fly with a yellow horizontal anchor under which are two yellow wavy lines representing the sea-going character of this auxiliary.

The Royal Navy relies for direct support at sea on the Royal Fleet Auxiliary which has existed for over 60 years, and its role is well known. Less is known about the other large supporting organisation, which operates under the title of Marine Services, embracing a wide variety of tasks from harbour services to ocean salvage. This support organisation operates over 600 vessels and employs nearly 6,000 personnel.

In 1958 most of the Marine Services vessels engaged on harbour services or work in estuarial waters were amalgamated to form the Port Auxiliary Service (PAS). The amalgamation has been very successful.

NOTICE TO READERS

The Editor extends to all readers of the Journal a cordial invitation to contribute articles of R.N.S.S., naval or general scientific and technical interest.

Authors are requested particularly to note that as the Journal is in the Restricted category the printing of material within its pages does not constitute open publication and does not prejudice the subsequent use of the material in the Journal of a learned society or institution, or in the scientific and technical press.

Manuscript should be typewritten if possible, in double spacing and on one side of the paper only. It should include, in addition to the title, the name of the Author together with initials, degrees and department, establishment or ship. Pseudonyms are acceptable only in special circumstances. A convenient length is between 3,000 and 5,000 words, but other lengths are acceptable and no contribution would be debarred on this ground alone. Illustrations are in most cases a desirable addition. Photographs should be of good quality, glossy, unmounted and preferably between two and three times the size of the required final picture. Graphs and line drawings should be made on a similar large scale, with bold lines to permit reduction in block making. A recent photograph and biographical note of the Author(s) will also be welcomed.

Views and opinions expressed in the Journal are not necessarily endorsed either by the R.N.S.S. or by the Editor.

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